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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Studies on Pilot Workload

Edited by
R.Auffret

NORTH ATLANTIC TREATY ORGANIZATION

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6 STUDIES ON PILOT WORKLOAD.

Edited by

10

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PREFACE

En 1976, l'ASMP/AGARD a décidé à la demande du Comité "Sciences du Comportement" d'organiser une réunion sur les charges de travail des pilotes.

Cette session a été divisée en deux parties:

- Méthodes de mesure de la charge de travail.
- Etudes de la charge de travail des pilotes.

Ces 2 sessions sont donc complémentaires, les "Etudes de la charge de travail des pilotes" souhaitant avoir un caractère plus concret, plus appliqué au travail de l'aviateur dans des situations réelles opérationnelles ou lors de vols simulés.

La nécessité de mieux connaître la charge de travail du pilote est chaque jour plus grande car les progrès de l'aéronautique, de l'avionique, des armements, de l'électronique . . .:

- procure une complexité croissante des avions et des hélicoptères;
- développe une sohpistication poussée des systèmes d'armes;
- augmente le nombre des informations à traiter par le pilote;
- modifie en permanence les systèmes de présentation, sans automatiquement les simplifier.

La rançon de ces progrès a pour conséquence de rendre les missions plus difficiles plus stressantes, parfois aux limites des possibilités humaines.

Malgré les nombreuses publications existantes, l'actualité du sujet persiste. Elle est même accrue de nos jours:

- pour les hélicoptères, par l'utilisation opérationnelle de l'hélicoptère à basse altitude en "rase-motte", par son emploi en condition de vol sans visibilité ou de nuit,
- pour les avions, par l'avènement d'une nouvelle génération d'avions avec possibilité de manoeuvrabilité considérable donc générateur d'accélérations importantes.

La finalité des "Etudes de charge de travail" est d'essayer de quantifier la somme de travail que peut fournir un pilote à chaque instant en le replaçant dans l'environnement physique particulier de l'avion (température, bruits, vibrations, accélérations . . .) et aussi dans le contexte psycho sociologique et affectif . . . Ces diverses variables peuvent en effet avoir une influence importante sur les performances humaines.

Pour le meeting de Cologne (avril 1977) 12 communications ont été sélectionnées et rassemblées dans une session d'une journée le 21 avril 1977.

PREFACE

In 1976, at the request of the "Behavioural Sciences" Committee, the ASMP/AGARD decided to arrange a meeting on the work-loads of pilots. This session was divided into two parts:

- Methods of measuring the work loads
- Studies of the work loads of pilots.

These two sessions are therefore complementary, the "Studies of the work-load of pilots" aimed at being of a more concrete nature, more applicable to the work of the airman in real operational situations or in simulated flights.

The necessity for a better knowledge of the work load of the pilot becomes more important every day as the progress in aeronautics, avionics, armament, electronics . . .

- brings increasing complexity to aircraft and helicopters;
- develops an advanced sophistication of weapon systems;
- increases the amount of information to be dealt with by the pilot;
- continuously changes the presentation systems without automatically simplifying them.

As a consequence the penalty for this progress is to make the missions more difficult, with more stress, sometimes up to the limits of human capabilities.

Despite the numerous existing publications, the topicality of the subject endures. It is even increasing today;

- for the helicopters, by the operational use of the helicopter at low altitude in "nap of the earth" mode, by its use in night flights or flying blind,
- for the aeroplanes, by the arrival of a new generation of aeroplanes with considerable manoeuvring capabilities, thus generating high acceleration loads.

The end in view of the "Work-load Studies" is to attempt to quantify the sum of work which the pilot can provide at each moment by putting him back into the special physical environment of the aircraft (temperature, noise, vibration, acceleration . . .) and also in the psychosociological and affective context . . . These different variables can, in fact, have a considerable influence on the human performance.

For the Cologne meeting (April 1977) 12 papers have been selected and combined into a one-day session for the 21st April 1977.

AEROSPACE MEDICAL PANEL

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Panel Executive:	Lt Colonel F.Monesi, IAF

MEETING ORGANIZATION

Host Coordinator and Program Organizer:	Dr med. K.E.Klein

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* Not presented at meeting.

RESUME

La session consacrée aux "Etudes de la charge de travail de pilote" a rassemblé douze communications.

Six communications concernent l'évaluation de la charge de travail sur hélicoptère montrant ainsi l'importance et les difficultés nouvelles des missions opérationnelles sur hélicoptère. Elles comprennent une étude générale des contraintes particulières du pilotage de l'hélicoptère (B1), les problèmes posés par le vol à basse altitude (B2 et B3), par les vols de longue durée (B4), par l'atterrissage et le pilotage sans visibilité (B5 et B6).

Cinq communications sont consacrées à des problèmes spécifiques aux avions, vol de longue durée sur avion de combat lors de déploiement transocéanique (B7), coût métabolique et endocrinien du vol sur avion de combat (B8), nouveau système de visée pour tir air sol (B9), appontage de nuit au cours de campagnes opérationnelles prolongées sur porte-avions (B10), qualité de vol et charge de travail sur avion de transport court courrier (B11).

Une communication étudie par questionnaire dirigé les caractéristiques particulières du travail des différentes catégories de pilotes (B12).

SUMMARY

Twelve papers were selected for the session devoted to "Studies of the work-load of the pilot".

Six of these relate to the evaluation of the work-load on the helicopter, thus revealing the importance and the new difficulties of helicopter operational missions. They comprise a general study of the stresses peculiar to helicopter piloting (B1), the problems raised by low altitude flight (B2 and B3), by long duration flights (B4), by blind flying and landing (B5 and B6).

Five papers are devoted to problems specific to aeroplanes; long duration flight in a combat aircraft in trans-oceanic deployment (B7), metabolic and endocrinal cost of flight in a combat aircraft (B8), new aiming system for air-to-ground firing (B9), deck landing at night during prolonged operational campaigns on aircraft carriers (B10), flight quality and work-load on a short-haul transport aircraft (B11).

One paper studies by a selectively directed questionnaire the special characteristics of the work of different categories of pilots (B12).

RAPPORT D'EVALUATION TECHNIQUE

par

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Le rapport d'évaluation technique comportera trois parties:

– Présentation des communications en les replaçant dans le contexte des "Etudes de charge de travail du pilote".

– Analyse et résumé des communications.

– Conclusions et recommandations.

Presentation des Communications

Le travail du pilote peut se résumer en trois types d'action:

(1) – *Acquisition des données* indispensables au pilotage de l'avion et à l'accomplissement de la mission. La meilleure appréciation en est donnée par la mesure des informations du système *avion* qui "entrent" dans le pilote. Ces entrées sont surtout visuelles d'où l'intérêt de la mesure des mouvements oculaires à l'aide d'oculomètre (B2) ou des mouvements de la tête à l'aide d'un film (B3).

(2) – *Analyse de la situation par le pilote* à partir des informations acquises. Les modifications subies au niveau pilote entre les "entrées" et les "sorties" (généralement action sur une commande) peuvent donner une estimation de cette action, par exemple, fonction de transfert. De même, l'étude des variables physiologiques, fréquence cardiaque (B5) des modifications métaboliques et endocriniennes (B7) (B8) peuvent rendre compte de cette étape du travail. Une tâche secondaire permet aussi d'apprécier la disponibilité du pilote (B2) (B9).

Les études subjectives par questionnaires dirigés: mesures de la fatigue, de l'humeur, du sommeil (B4) (B7) (B10) (B11), des difficultés de la tâche (B5) ou du travail avec des modes de présentation d'informations différentes (B6) (B9) ou d'analyse des qualités de vol (B5) (B11) sont donc fréquemment utilisées.

(3) – *L'action du pilote* sur une commande, suivant une stratégie, fonction de l'expérience et de l'entraînement, pour atteindre l'objectif fixé, consistera le plus souvent, en une mesure de performances, identification des points survolés (B2), précision du vol stationnaire (B4), écart par rapport à une trajectoire idéale ILS (B5), précision des paramètres imposés du pilotage (B6), temps d'acquisition et précision de la poursuite de la cible sur divers modes de présentation (B9).

En fonction de sa durée, le travail du pilote comporte:

– une charge de travail à court terme, comprenant une phase de vol, par exemple atterrissage, décollage, approche (B3), (B4) et (B5), tir d'engins (B9) . . .

– une charge de travail à moyen ou long terme, provoquée par la répétition des phases de vol, avec un seul vol ou répétition des vols sur une journée ou période de travail plus longue, mettant en jeu rythme veille-sommeil, décallages horaires . . . (B4), (B7) et (B10).

Les diverses communications étant placées dans leur contexte, nous pouvons maintenant en faire l'analyse et le résumé.

Analyse et Resume des Communications

B-1, Rotondo analyse les paramètres physiques et physiologiques de la charge de travail des pilotes d'hélicoptère. Il attire l'attention sur les aspects liés à l'environnement particulier de l'hélicoptère (vibrations, bruits) et sur les facteurs psychoémotionnels de certains vols d'hélicoptère qui déterminent une fatigue aussi importante que sur les avions de combat.

B-2, Sanders et col. décrivent le travail visuel du copilote navigateur lors des vols basse altitude en hélicoptère. Les mouvements oculaires enregistrés par un collimateur NAC permettent de connaître le temps passé à regarder à l'intérieur (instruments du cockpit), à regarder à l'extérieur de l'habitacle (repères extérieurs) et à lire la carte. Une tâche secondaire visuelle apprécie le temps libre disponible au cours de la mission

B-3, Lovesey enregistre en vol l'activité des mains et de la tête du pilote lors de vols à basse altitude en hélicoptère. Sa technique de prises de vue, n'interfère pas avec le travail du pilote. Elle montre que l'activité du pilote est d'autant plus importante que le vol a lieu plus près du sol.

Dans cette situation particulièrement délicate, évitement des obstacles, des lignes à haute tension, des arbres, des positions ennemies . . . 1/3 du temps est passé à regarder dans la cabine, carte, instrument, radio . . . !!! Ce travail déjà marginal, au plan de la sécurité, à cause de la mauvaise conception ergonomique de la cabine est aggravé par le port d'équipements de vol spéciaux (combinaison de protection, guerre chimique, par exemple).

B-4, Lees et col. apprécient la précision de la performance des pilotes d'hélicoptères lors des vols de longue durée avec et sans déprivation de sommeil par une mesure de performance (précision du vol stationnaire) et par des mesures subjectives de fatigue à l'aide de questionnaires.

B-5, Vettes au cours d'approches I.L.S. de difficulté croissante sur hélicoptère n'a pas réussi à obtenir de corrélations entre les variations de la fréquence cardiaque et les impressions subjectives des pilotes quantifiées par une échelle du type Cooper-Harper.

B-6, Beyer a rappelé l'influence de la présentation des informations sur la charge de travail dans deux conditions expérimentales très différentes sur hélicoptère:

– Comparaison de 2 "Head up display" sur 15 pilotes pendant un petit nombre de vols à l'aide de questionnaires.

– Comparaison entre "Head down display" sur écran T.V. et pilotage à vue par des mesures de performance et avis subjectifs de 2 utilisateurs pendant un grand nombre de vols.

B-7, Hartman et col., au cours de déploiements transocéaniques sur avions de combat, déterminent la fatigue et le stress des équipages à l'aide d'une batterie de mesures comportant: échelle subjective de fatigue, échelle subjective d'aptitude à remplir la mission, temps de sommeil, analyse biochimique des urines. Même, à l'issue de la fatigue importante faisant suite à ces vols, la récupération est pratiquement totale après une nuit de sommeil.

B-8 – B-9, Wegmann et col., ainsi que Manville, absents, excusés, n'ont pu présenter leurs communications respectivement intitulées:

– "Coût endocrinien et métabolique de pilotage sur F.104.G".

– "Un nouveau système de visée tir air-sol apportant une meilleure précision et une charge de travail moindre".

B-10, Brictson, cherche à mieux connaître la performance et l'efficacité des pilotes lors des appontages de nuit sur porte-avions au cours de campagnes opérationnelles prolongées en les reliant à l'appréciation de l'état psychotemporel des pilotes (sommeil, humeur, heures de vol, expérience acquise). La méthodologie employée permettrait de fournir une bonne prédiction de la performance lors des missions opérationnelles.

B-11, Steininger apprécie les qualités de vol d'un avion de transport court courrier et la charge de travail des pilotes à l'aide d'un questionnaire (82 questions) et d'interview.

B-12, Goerres, évalue subjectivement les divers éléments de la charge de travail des différentes catégories de pilotes par un important questionnaire de 170 questions posées à 217 pilotes de la G.A.F.

Conclusions et Recommandations

Au cours de ce symposium, les difficultés de mesures quantitatives de la charge de travail et l'impossibilité de la performance lors de charges de travail importantes et de longue durée sont apparues. Au plan opérationnel, il faut cependant noter que la récupération d'une seule nuit apporte restitution presque complète des possibilités humaines (B7). Devant l'absence de solution globale du problème il convient de mettre en oeuvre une batterie de tests ou du moins d'associer à toute étude subjective, une méthode objective (mesure de la performance) afin d'essayer de trouver des corrélations.

Un certain nombre de principes et recommandations se dégagent de l'ensemble des communications:

– limiter l'emploi des méthodes qui risquent d'interférer avec le travail des pilotes et de modifier sa performance par la gêne qu'elles apportent: limites de l'utilisation des oculomètres actuellement sur le marché (utilisation douloureuse après 10 minutes).

– Choix des méthodes déjà bien étalonnées et couramment utilisées par les laboratoires qui les mettent en oeuvre; ceci est particulièrement vrai pour les méthodes psychométriques, physiologiques, biochimiques qui ne donnent de bons résultats qu'entre les mains d'expérimentateurs spécialisés.

– Nécessité pour l'expérimentateur responsable des études de se rendre "sur le terrain" pour connaître les conditions opérationnelles réelles.

– Limites des corrélations entre les diverses méthodes proposées.

Il convient cependant de noter l'intérêt primordial de certaines méthodes au cours de situations opérationnelles particulières:

– *lors des vols Basse altitude sur hélicoptère:* Prises de vue du travail du pilote effectuées par un expérimentateur placé à côté du pilote lors des vols à basse altitude sur hélicoptère;

– *lors des vols de longue durée:* méthodes biochimiques, étude du sommeil et de l'humeur par questionnaire;

– *Pour les comparaisons d'instruments et de présentation d'informations:* mesure de performances et questionnaires dirigés.

TECHNICAL EVALUATION REPORT

by

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The technical evaluation report will be in three parts:

– Presentation of the contributions by placing them in the context of the "Studies of the work-load of the pilot".

– Analysis and summary of the contributions.

– Conclusions and recommendations.

Presentation of the Contributions

The work of the pilot can be summarised in three typical actions:

(1) – Acquisition of data necessary for flying the aircraft and accomplishing the mission. The best assessment of this is the measurement of the information from the *aircraft* system which "enters" into the pilot. These inputs are predominantly visual, hence the value of the measurement of ocular movements with the oculometer (B2) or of the movements of the head by means of a film (B3).

(2) – *Analysis of the situation by the pilot* from information acquired. The modifications undergone at pilot level between the "inputs" and the "outputs" (generally action on a control) can give an estimate of this action, for example, transfer function. Similarly, the study of physiological variables, cardiac rate (B5), of endocrinal and metabolic changes (B7) (B8) can provide an account of this stage of the work. A secondary task also enables the availability of the pilot to be assessed (B2) (B9).

The subjective studies by orientated questionnaire: measurements of fatigue, humour, sleep (B4) (B7) (B10) (B11), the difficulties of the task (B5) or of the work with different modes of information display (B6) (B9) or analysis of flight quality are therefore frequently used.

(3) – *The action of a pilot on a control*, according to a strategy, function of experience and training, to attain the fixed aim, will usually consist in a measurement of performance, identification of the points overflown (B2), accuracy of hovering flight (B4), deviation from an ideal ILS flight path (B5), accuracy of the parameters set by the flying (B6), acquisition time and accuracy of tracking of the target on different modes of display (B9).

In terms of its duration the work of the pilot comprises:

– a short term work-load, comprising a flight phase, for example, landing, take-off, approach (B3) (B4) and (B5), missile firing (B9) . . .

– a moderate or long term work-load, caused by repetition of the flight phases, with a single flight or repeat of flights over a day or longer working period, setting into action a watchful-drowsiness rhythm, time-shifts . . . (B4), (B7) and (B10).

The various papers being placed in their context we can now summarise and analyse them.

Analysis and Summary of the Communications

B-1, Rotondo analyses the physical and physiological work-load of helicopter pilots. He draws attention to the aspects connected with the particular environment of helicopters (vibration, noise) and to the psycho-emotional factors of some helicopter flights which result in fatigue as great as in combat aircraft.

B-2, Sanders et al. describe the visual work of the navigator copilot in helicopter low altitude flight. The ocular movements recorded by an NAC collimator enabling knowledge to be obtained of the time spent in looking inside (cockpit instruments) and outside the cockpit (external reference points) and in reading the map. A secondary visual task assesses the free time available during the mission.

B-3, Lovesey records in flight the activity of the hands and head of the pilot in helicopter low altitude flight. His technique of photographing does not interfere with the work of the pilot. It shows that the activity of the pilot is the greater as the flight is nearer the ground.

In this particularly tricky situation, avoiding obstacles, high voltage lines, trees, enemy positions . . . 1/3 of the time is spent looking in the cabin, map, instruments, radio . . .! This work, already marginal in respect of safety, because of the poor ergonomic design of the cabin, is aggravated by the carriage of special flight equipment (combination of protection, chemical warfare, for example).

B-4, Lees et al. assess the accuracy of the performance of helicopter pilots in long duration flights, with and without deprivation of sleep, by a performance measurement (accuracy of hovering flight) and by subjective fatigue measurements by questionnaires.

B-5, Vettes, during ILS approaches of increasing difficulty in a helicopter, did not succeed in obtaining correlations between the variations of cardiac rate and the subjective impressions of pilots quantified by a scale of the Cooper-Harman type.

B-6, Beyer recalled the influence of the information display on work-load in two very different experimental conditions in helicopters:

– Comparison of two "Head up displays" on 15 pilots during a small number of flights, by using questionnaires.

– Comparison between "Head down display" on TV screen and visual flying, by measurements of performance and subjective opinions of two users during a large number of flights.

B-7, Hartman et al. during trans-oceanic deployment in combat aircraft determine the fatigue and stress of crews by means of a battery of measurements, including: subjective fatigue scale, subjective scale of aptitude in fufilling the mission, sleep time, biochemical analysis of urine. Even after considerable fatigue following these flights recovery is practically complete after a night of sleep.

B-8, B-9, Wegmann et al. and also Manville, with apologies for absence, were unable to present their papers, entitled:

– Endocrinal and metabolic cost of flying on F.104 Gs.

– A new system of air to ground firing aiming giving better accuracy and a lower work-load.

B-10, Bricton seeks better knowledge of the performance and efficiency of pilots in night deck-landings on aircraft carriers during prolonged operational campaigns by relating them to the assessment of the psychotemporal state of pilots (sleep, humour, flight hours, acquired experience). The methodology employed should enable a good prediction to be obtained of performance in operational missions.

B-11, Steininger assesses the flight qualities of a short haul transport aircraft and the work-load of the pilots by a large questionnaire of 170 questions put to 217 pilots of the GAF.

Conclusions and Recommendations

During this symposium, the difficulties of quantitative measurement of the work-load and the impossibility of predicting the decrement of performance with considerable work-loads and those of long duration have been revealed. At the operational level it must, however, be noted that recuperation in a single night brings almost full recovery of the human capabilities (B7). *In the absence of an overall solution to the problem it is necessary to employ a battery of tests,* or at least to associate with every subjective study an objective method (performance measurement) in an attempt to find correlations.

A number of principles and recommendations emerge from these communications:

– to limit the use of methods which risk interfering with the work of the pilot and change his performance by the trouble they cause: limits of the use of the oculometers at present on the market (use painful after 10 minutes).

– choice of methods already well calibrated and currently used by the laboratories which implement them; this is particularly true for the psychometric, physiological and biochemical methods which give good results only in the hands of specialised investigators.

– Necessity for the investigator to be personally on the spot to know the actual operational conditions.

– Limits of correlations between the various methods proposed.

It is necessary, however, to note the prime importance of some methods in special operational situations:

– *In helicopter low altitude flights:* Photographs of the work of the pilot taken by an investigator at the side of the pilot during helicopter low altitude flights;

– *In flights of long duration:* Biochemical methods, studies of sleep and of humour by a questionnaire;

– *For comparisons of instruments and information displays:* measurements of performance and selectively orientated questionnaires.

WORKLOAD AND OPERATIONAL FATIGUE IN HELICOPTER PILOTS

by

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SUMMARY.

After a rapid review - in the light of modern aetiopathogenetic views - of the possible causes of the operational fatigue to which air crews generally become subject during the performance of their flying duties, the author describes and analyzes in greater detail the nature and the entity of the various stressing factors that constitute the physical and psychic workload of the modern helicopter pilot in the carrying out of his professional activity.

As regards this particular sector of flying, the author then proceeds to make an analytical examination of the influence that the various traumatic and fatiguing effects of the vibrations, the noises and the psycho-emotive and psycho-sensorial factors connected with the multiplicity and the dangers of this modern means of air transport - nowadays in constant technical evolution and employed in ever wider fields - exert, both singly and jointly, on the genesis of flying fatigue in helicopter pilots.

On the basis of this analytical survey it is possible to conclude that the piloting of helicopters involves a psycho-physical workload that is certainly not inferior to the one experienced by the pilots of faster and more powerful aircraft.

PRELIMINARY REMARKS, DEFINITION AND AETIOPATHOGENESIS OF PILOT FATIGUE.

It is a well known fact that flying activities, here understood as a "vital" activity rather than a technical and operational one, subject the organism of the pilot to both physical and psychic stress as a result of the performance of a type of work that has the special characteristic of having to be carried out in particular coenesthetic and environmental conditions, of involving a high degree of psychological tension and a considerable and prolonged concentration of the pilot's attention, and of being accompanied by a particular emotional state.

Just as in the case of any other type of working activity, all this may give rise to a state of fatigue that, in the special terminology used in aerospace medicine, is commonly known as "pilot fatigue", "flying fatigue", or "operational fatigue".

Since the term "fatigue" is generally understood (FRYER, 1971,6) to refer to a state of decrease and deterioration of nervous, muscular or sensorial activity due to a prolonged and recent stimulation and activity, the whole associated with a diminished capacity for physical or mental work and an unpleasant feeling of tiredness as a result of physiological exhaustion, boredom, loss of motivation or emotional factors, the particular case of "pilot fatigue" may be *defined as the state in which, as a result of either a prolonged* or an intense flying activity, there occurs a deterioration of the pilot's performance : a deterioration that involves an increase of the energy cost or the effort needed to attain a given level of efficiency, and accompanied by a typical and subjective feeling of tiredness, loss of energy, mental inertia, tension, irritability, with a consequent desire to interrupt the flying activity. The precise scheme of these effects, in turn, depends on the pilot's motivation and also on whether his work is predominantly of a physical or a mental nature.

In the specific case of flying fatigue, in fact, it is possible to identify a number of different components :

a) a physical component, the result of motorial, perceptive or neuromuscular work ;
b) a psychic component, the result of mental work and prolonged psychic tension, and lastly
c) an emotive component, the result of exposure to the repeated and intense emotions that are inevitably connected with the performance of an activity that continuously places the *physical ego* in peril and with the abnormal coenesthetic *stimulations* of the external and the internal environment, stimulations that are often excessive in intensity, kind and duration.

We therefore have a multitude of different factors that, either singly or in association, may constitute the causes of fatigue during the carrying out of flying and, as a result of the repetition and summation of their effects in time, contribute to bringing about a considerable workload and a certain physiopsychic exhaustion of the pilot.

Leaving aside a number of factors that, although they undoubtedly aggravate fatigue, are common to other types of activity and not therefore exclusively associated with flying, including inadequate nourishment, insufficient rest or lack of sleep, worries associated with family, career or money, abuse of alcohol, tobacco or other stimulants, etc., the following stimulations may be recalled as being exclusively due to the flying activity

and of a particularly fatiguing nature : the effects of variations of altitude and barometric pressure during high-level flights ; the effects of accelerations during high-speed or acrobatic flying ; the effects of acoustic and non-acoustic vibrations, of light radiations, of changes of temperature and variations of the weather conditions, of air sickness, etc.; but more than anything else, as has already been suggested, the continuous psychic tension involved in the management of the aircraft and the performance of the aeronautical navigation even in normal conditions, associated with the frequent and intense emotional states that occur during any flight, and all the more so during specially demanding and difficult flights, act as psychic microtraumas and can therefore alter the affective equilibrium of the pilot and provoke a psychic exhaustion in the true sense of the word, with possible somatopsychic manifestations and consequent repercussions of a neurovegetative and sometimes even a neuroendocrine nature.

As regards, more particularly, the actual location of the fatigue phenomenon, one has to bear in mind (ROTONDO, 1969,31) that a preponderant part of the work involved in piloting an aircraft, just as in any other similar activity (driving a racing car, for example), makes demands on the central nervous system of the pilot.

In actual practice, indeed, the piloting of an aircraft (or of any other high-speed vehicle) is the result of a series of conditioned reflexes and acts that have become substantially automated ; the engrammes of these acts and reflexes were formed during apprenticeship and training, and they must be regarded as located in the highest segments of the central nervous system, especially in the cerebral cortex.

On the other hand, the expletion of these conditioned reflexes also calls for a considerable degree of coordination and readiness of the lower parts of the nervous system, i.e. at the level of the efferent nerves governing motorial activity, and requires the entire skeletric musculature to be in good working order.

In the case of the piloting of an aircraft, however, it is not possible to speak of <u>muscular fatigue</u> in the true sense of the word, since this phenomenon (except in particular and in any case exceptional situations) is not normally very pronounced in a pilot or, at least, does not involve large masses of muscles ; in such cases it would therefore be more proper to speak of a <u>neuro-muscular fatigue</u>, that may at least in part be caused by the obligatory tone that the entire skeletric musculature is forced to assume during the prolonged and more or less complete immobility associated with the pilot's position in the cockpit seat and the consequent state of tension that characterizes a goodly part of the motorial nerves for the entire lenght between their spinal origins and their peripheral terminations at the level of the neuromuscular synapses.

But a good part of the operational fatigue of aircraft pilots may be due not only to neuro-muscular fatigue but also and even more so to a <u>nervous fatigue</u> in the true sense of the word, a fatigue that would seem to consist of a functional depression of the cortical activity, this latter, in turn, brought about by the functional exhaustion of the neurons of the cerebral cortex ; these neurons, indeed, have to accomodate the passage of the numerous pulses required to keep the cerebral activity constantly alert and vigil and to adapt it to the multiple and complex functional demands connected with the management and control of the aircraft. Alternately, this fatigue could be interpreted as the consequence of a state of supertension of the neurons themselves, which are overloaded by the numerous stimuli of a psychic and emotional nature that are characteristic of as demanding an activity as the piloting of an aircraft.

In this latter case, in other words, we may be concerned not so much with a fatigue of the sensorial and motorial functions in the physiological sense, but rather with a <u>psychic fatigue</u> that comes into play as one of the principal components of the socalled nervous fatigue, whose other important components are represented - as has already been pointed out - by <u>mental fatigue</u> (since the piloting of an aircraft calls for the intervention of upper psychic processes and for a constant and prolonged commitment of the pilot's attention, which leads to a prolonged psychic tension) and, above all, <u>emotive fatigue</u> (as a result of the many emotional microtraumas which, in the long run, affect the biological nucleus of affectivity.

These emotive factors could well be among the principal one's responsible for pilot fatigue, not least because this very mechanism of emotion produces certain peripheral physiological effects that are undoubtedly to a substantial extent responsible for that state of subjective suffering that is characteristic of fatigue, effects that are due to the action of these psychic and emotive pulses that act through the channels that run from the cortex to the vegetative centres in the thalamus and the hypothalamus, producing effects that may be attributed to excitation of the sympathetic and/or the parasympathetic, depending on the particular predisposition of the individual, and sometimes also to a participation of the neuroendocrine system, first and foremost through an intervention of the axis between the hypophysis and the suprarenal glands.

ANALYSIS OF THE POSSIBLE CAUSES OF OPERATIONAL FATIGUE IN HELICOPTER PILOTS.

Having summarily examined the nature and the probable physiopathogenetic causes of flying fatigue in general, it seems to us that an interesting analytical inquiry would be constituted by the study of the influence that each of the aforementioned fatiguing and exhausting factors exerts on the genesis of operational fatigue in the particular case of helicopter pilots, this especially in view of the altogether particular modalities of the operational use of this type of flying vehicle that, on account of its outstanding versatility and handling characteristics, has recently been finding ever increasing employment in both the military and the civil field.

In fact, given the multiplicity of employments that are made possible by this exceptional manoeuverability, it is quite obvious that we are here concerned with an altogether particular and original flying vehicle, a means of transport whose continuous evolution enables it to absolve an ever increasing number of tasks ; these tasks range from the normal transport of men and equipment to the transport and evacuation of sick and wounded people, to employment for rescue operations at sea and in the mountains, to use in warfare, and to a variety of employments in the civil field, agriculture, industry and publicity being cases in point.

Seeing that we are here concerned with a modern and relatively recent means of transport that is less well known than the various types of fixed-wing aircraft, it may therefore be interesting to analyze the possible causes of operational fatigue in helicopter pilots and to try to identify the specific fatiguing factors that are inherent in the carrying out of this particular type of flying activity.

A. Effects of Stresses and Stimuli common to all types of flying.

First of all, as regards the effects of accelerations and variations of speed, altitude, pressure and temperature, air sickness, etc., all of which exert a well known direct and indirect influence on the genesis of flying fatigue in the case of the greater part of conventional aircraft, and particularly those operated by jet engines, it is immediately obvious that their influence must be much smaller in the case of helicopters : indeed, given the considerable limitations of speed, altitude and range to which this type of vehicle is subject, it can perform only relatively limited and slow displacements in altitude, latitude and longitude.

However, some importance may attach, especially in hot climates, to the excessive heating of the hoods and cabins of helicopters due to the vehicle being parked for a long period of time in the open and therefore exposed to the sun in summertime (especially in tropical regions) ; but the problem of overheating due to excessive exposure to the sun is something that helicopters have in common with other types of aircraft.

But considerable importance may attach to certain other factors that assume a special and altogether particular physiognomy when helicopters are used ; these include the effects of vibrations and noise and the effects of psycho-emotive and psycho-sensorial factors associated with flying this type of airborne vehicle.

B. Effects of Vibrations.

As regards the vibrations and the noises, we are concerned with an extremely complex problem that assumes particular importance in the case of helicopters ; indeed, the vibration phenomena may be said to be characteristic of helicopters, even though continuous technical improvements are tending to produce a steady reduction of their capacity to cause harm to the inmates of the helicopter.

As is known, the helicopter vibrations are characterized by a frequency that, depending on the type, may range from 280 to 320 Hz and an amplitude that varies as a function of the balancing of the rotor blade or, as this is normally put in technical language, the proper tracking of the two halves of the rotor. This vibration is a vertical one and becomes more accentuated when, as often happens, the two halves of the rotor are not in perfect track. During helicopter flight, in fact, both the pilot and the passengers keep moving their heads forward and backward, almost as if they were continuously nodding in assent.

Although there exist many other vibrations of a cyclic type and various frequencies, including horizontal vibrations and the variable vibrations that depend on the relative wind and the ground resonance, these vertical vibrations undoubtedly remain the most important ones as regards repercussions on the organism of the pilot.

According to current terminology, however, one can distinguish several varieties of vibrations produced by helicopters and characterized by the following definitions :

a) Vertical, constant, one per rotor revolution : about six beats per second ; is felt like a vertical "rebound" and manifests itself in perfect synchronism with each revolution of the rotor. The pilot and the passengers lift and drop in unison.
b) Lateral, one per revolution : similar to the vertical vibration, but with the difference that the pilot and the passengers lift and drop out of phase ; this phenomenon is more obvious when it is observed from the rearmost seats.

c) Mixed, one per revolution : this manifests itself intermittently, once per revolution, but the individual beats may be irregularly spaced. Beats of a certain amplitude may become superposed in a random manner on a vertical and costant vibration, one per revolution. Sometimes the phenomenon is more obvious at the cruising power. It generally occurs on the occasion of rapid manoeuvres and in turbulent air ; indeed, it may be confused with the presence of turbulence.
d) Two per revolution : about twelve per second, difficult to count ; they have approximately the same frequency as a pneumatic hammer.
e) Six per revolution or at a high frequency : impossible to count. These vibrations assume the character of a "buzz".
f) Oscillations of the rotor shaft : about three per second or one every two revolutions. This type of motion recalls that of a rocking chair ; it generally occurs during an ascent or when flying at high power. It may be unwittingly induced by the pilot, i.e. when he causes slight to and fro motions of the control stick. In such cases it is best to increase the friction of the control stick in order to minimize the effects of the impacts caused by the pilot.

When studying the effects of the vibrations and their influence on the genesis of flying fatigue in helicopter pilots, one also has to bear in mind that, both in helicopters and other types of aircraft, the persons transported are not only subjected to the vibrations caused by the motive force that is transmitted to the passengers together with the secondary vibrations produced by the surrounding structures.

During flights through zones of perturbed atmosphere, for example, troublesome vibrations of variable frequency and amplitude may be provoked by local differences in the density and the temperature of the air. Every time the helicopter crosses such a zone, it suffers an impact that modifies its speed and may also cause it to be thrown considerably off course in any direction. These impacts distinguish themselves from the ones caused by the vibrations connected with the structure of the helicopter by virtue of the fact that they are of short duration, irregular, and intense. Their violence increases in denser air, i.e. close to the ground, and also in bad weather conditions.

As is known, the ultimate effect of prolonged and repeated exposure to vibrations of various frequencies and amplitudes may take the form of a wide range of disturbances that consist essentially of headache, buzzing ears, general discomfort, a feeling of dumbness and generalized asthenia, irritability, deterioration of the capacity to pay attention and to concentrate and of the will power in general, reduced rapidity of the reflexes, psychic depression, tiring of the eyes and ears : these disturbances, given their intensity and their persistence throughout the duration of the flight, may well be said to contribute in a decisive and preponderant manner to the genesis of operational fatigue in helicopter pilots.

Particularly troublesome and fatiguing is the effect that the vibrations acting on the whole body will eventually exert on the pilot's capacity of visual perception and, more particularly, on his acuity of vision : the veil that drops in front of his eyes as a result of the continuous vibrational motion of the helicopter will make it practically impossible for him to read the panel instruments or the flying charts at frequencies above about 15-20 Hz. It is well known that prolonged strain of the eyes leads inevitably to general fatigue within a short period of time.

Particular practical interest may also attach to the effects exerted on the acuity of vision by sinusoidal vibrations having a frequency of the order of 10 Hz and an amplitude in excess of 2.5 cm, this particularly during low-level flights, possibly in perturbed atmospheric conditions. In fact, SIMONS and SCHMITZ demonstrated in 1958 that vibrations of 2.5 and 3.5 Hz and values of the acceleration of the order of 0.17-0.30 g lead to a 10% reduction in visual acuity after 90 minutes. DRAZIN (1959, 5), likewise, demonstrated experimentally that vibrations of 2.7 cm amplitude cause a 10% drop in the acuity of vision when the frequency is 1 Hz, a 12% drop when the frequency reaches 2 Hz, while a frequency of 3 Hz leads to a 30% reduction ; further, with an amplitude of 5.5 cm, the acuity of vision is reduced by 12% at 1 Hz and by 20% at 2 Hz ; lastly, when the vibrations have an amplitude of 11.25 cm, the visual acuity diminishes by 15% at frequencies of 1 Hz, and by 25% at frequencies of 1.5 Hz.

These results may also be valid for those cases in which the pilot subjected to vibrations fixes his eyes on an immobile object at infinity (a distant reference point on the horizon for example) ; on the other hand, if the object is fixed but close to the pilot (a dial on the instrument panel for example), the acuity of vision will become reduced in a far more accentuated manner.

The motorial activity is also compromised by the action of the vibrations : in a helicopter, indeed, it becomes particularly difficult to perform the small movements needed for the control operations, especially when the oscillations are intense, of variable strength, and make themselves felt at irregular intervals.

Very intense vibrations may also provoke chest pains of an anginoidal type, visceral pains, and even occasional diarrhea with discharges of blood. The slow oscillations cause

a feeling of depression rather than disturbances in the true sense of the word. At basic frequencies of less than 1 Hz and amplitudes of several feet one can observe numerous cases of meteoropathy.

In addition to the phenomena of general fatigue and not feeling well, moreover, a chronic exposure to vibration may - as is well known - cause arthritic phenomena in the skeleton and, more particularly, the spine, associated with pains and reduction of the motility of the various body segments.

The limits of tolerability of vibrations are less well defined than those of the tolerability of centrifugal accelerations, and this mainly because the threshold values vary greatly from one subject to another, and because there is no simple relationship between tolerance and frequency. For example, at frequencies between 4 and 10 Hz there is an unusual sensitivity that can be attributed to the particular physical constitution of the human body, which in this part of the spectrum is characterized by a series of resonances, and to the fact that the vibrations of low frequency and great amplitude, which cause the thoracic and abdominal viscera to enter into resonance, have repercussions on the various body segments of the pilot and the members of the crew and can be responsible for syndromes peculiar to flying that, even though they are as yet barely known, are nowadays observed with increasing frequency.

At about 4.5 Hz, for example, the scapular arch and the upper part of the trunk oscillate more strongly than the remaining parts of the trunk (GUIGNARD and IRVING, 1959, 12) ; the abdominal organs, on the other hand, seem to react more markedly at rather low frequencies (COERMANN et al., 1960, 4). Minor resonances in unidentified structures deform the reaction curve of the organism at higher frequencies (HOWARD, 1967, 13).

C. Effects of Noise.

The action on the auditory functions of the flying crew of the noises due to the helicopter engines is almost as disturbing and fatiguing as the effect of the vibrations.

Experimental studies have been carried out by various authors, particularly BURDINAUD et al. (2), who in 1956 exposed unprotected probands to the noises of a Djinn helicopter for 20, 30, 60 and even 90 minutes, subsequently examining the modifications of the acoustic threshold by audiometric means. They found that the resulting loss of hearing presented the characteristics of a pure deafness and that about fifteen hours were required before the disappearance of the loss of hearing caused by an exposure for thirty minutes.

METCALF and WITWER (1958, 22) also highlighted the fact that, after two hours' flying in a helicopter capable of generating noises having a frequency between 50 and 2200 Hz and an average intensity of the order of 119 dB, the auditory threshold of their unprotected probands was raised by an average of 22 dB and that this higher threshold persisted for some 32 to 36 hours.

Another cause of discomfort and fatigue for the helicopter pilot deriving either directly or indirectly from the engine noises is connected with the use of the radio equipment. Some disturbances are caused by the pilot's earphones or by similar devices built into a protective helmet (excessive background noises, earphones not readily adjustable to pilot's head, poor protection against noise, earphones that hinder the dispersion of heat), others by the microphone (moisture sometimes condenses on the microphone). Even the mere fact that the earphones have to be kept on the head for a long period of time may give rise to a feeling of annoyance and local discomfort at the areas where the earphones make contact with the head : in this latter case, however, the disturbances are of very short duration and are readily remedied by removing the earphones or the helmet for a few minutes.

No matter what the origin of the noise in the helicopter [1], there can be no doubt that prolonged, repeated and systematic exposure to the noises of these rotor-powered flying vehicles, just like exposure to the noises of piston-engined or jet-engined [2] aircraft, will lead to auditory fatigue and thus exert a considerable influence on the coming into being and the subsequent aggravation of general fatigue.

As regards their biological effects, indeed, it has been known for a long time that noises act in a particular manner on the human ear, provoking - according to the duration and the intensity of the stimulation - states of adaptation, of auditory fatigue, of deafness, as well as other general effects on the various apparatuses and the central and peripheral nervous systems.

Considering acoustic damage in the true sense of the word, when the noises attain a certain intensity (of the order of 80 dB) and act for a certain length of time (at least

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(1) It is well known that the global noise of a generic piston-engined aircraft depends on the following constructional and functional characteristics : engine power, thrust, number of propeller blades, speed of the propeller tips, number of H.P. per propeller blade, etc.

(2) In the case of jet aircraft particular importance seems to attach to the sounds and ultrasounds produced by the aerodynamic turbulence of the jetstream, and by the rotation of the turbine and the compressor blades (when the engine is equipped with a compressor).

12-16 hours), they at first produce a state of adaptation that consists of a raising of the threshold of acoustic perception (TTS = Temporary Threshold Shift) ; if the noise persists, this threshold shift remains constant (ATTS = Asymptotic TTS) and continues at this level even after the exposure to the noise has ceased ; if the cessation of the noise exposure persists for a few days, however, the threshold value will return to its normal level.

Following repetition and prolongation of the exposure to the noise, on the other hand, the initial state of adaptation may give way to auditory fatigue, which may be defined as a diminution of the perceptive sensitivity due to a continuous stimulation of the auditory apparatus, a diminution that persists for some time after the cessation of the noise that has brought it about, but is then followed by a period of recovery, rather rapid at first, later markedly slower, possibly even with interruptions or short reversals. There is a clear correlation between fatigue and intensity of the stimulus, and this becomes particularly obvious above 60 dB ; an equally clear correlation exists between fatigue and the duration of the stimulus.

Given exposure to even more intense noises, in excess of 90 dB say, a true acoustic trauma may occur, a state characterized by the fact that a true auditory scotoma appears in the audiogramme. At frequencies in excess of 800 Hz, this scotoma has its maximum extent half an octave below the stimulating frequency ; in the case of complex noises the maximum occurs around a frequency of 4000 Hz, while in the case of noises of limited frequency it may sometimes be found in a different frequency zone.

If the exposure to noise becomes habitual, subjects having a special predisposition may, in the absence of adequate protection, reach an ultimate stage consisting of occupational deafness in the true sense of the word ; in that case the TTS has become transformed into a PTS (Permanent Threshold Shift) and we are concerned with an irreversible form of acoustic damage.

The various periods of the coming into being of this permanent damage, i.e. total latency, sub-total latency and manifest deafness, are influenced in their rate of evolution by a variety of concurrent and concausal factors that may be either endogenous (individual susceptibility, age, previous ear affections) or exogenous (intensity, frequency and rhythm of the noise, and working conditions).

Apart from the local effects on the auditory apparatus, it is well known that noises may also exert general actions on other apparatuses : on the central nervous system, for example, with modifications of the chronaxia and the reflexes and the reaction times, variations of the circulation and the endocranic pressure, electroencephalographic anomalies, and neuromuscular and psychic disturbances ; on the circulatory apparatus, with variations of the cardiac frequency and rhythm, of the arterial pressure, and electrocardiographic anomalies ; on the respiratory apparatus, with modifications of the rhythm and the frequency of the breath, and sometimes with apnea, followed by polypnea ; on the digestive apparatus, with variations of the secretion of saliva, the gastric motions and secretions, the motor activity of the intestine, etc. (circulatory, respiratory and digestive disturbances that may all derive from hyperreflexivity of the orthosympathetic system).

We have already mentioned the considerable influence that prolonged and repeated exposure to aircraft noises in general, and therefore also to helicopter noises in particular, may exert, through the establishment of a state of auditory fatigue, on the genesis and evolution of flying fatigue.

According to COERMANN et al. (1960,4), the phenomenon of fatigue induced by noise can, in fact, be explained as the final outcome of a victorious struggle of the noise against the other pulses that reach the encephalus at the same time. The greater concentration needed to capture these desirable pulses implies an excessive expenditure of energy and leads rapidly to a nervous fatigue.

The observable manifestations of this nervous fatigue are the previously mentioned neurological phenomena that can be objectivized by means of exposure to noises similar to those produced by aircraft ; these phenomena include the diminution of the chronaxia of motor nerves (GRANDPIERRE and LEMAIRE, 1947,9), the lengthening of the "average time" of simple reaction and the increase of the "average variation" of the reaction itself, i.e. the number of errors and the inconstancy of the motorial reaction (STROLLO and DEBARNOT, 1957,35), and lastly the attenuation of the patellar reflex (CAPORALE, 1959,3) ; this latter phenomenon, however, is not observed when the subjects exposed to the noise have been protected by means of ear covers and can be interpreted as an exhaustion phenomenon that is secondary to an earlier phase of nervous hyperexcitability.

From this one can deduce that the noises exert their fatiguing action on the nervous system, which in the long run also becomes an exhausting action, primarily through the mediation of the ear. Indeed, TIZZANO (1958,36) affirms in this connection that "the ear is not a closed vessel that merely gathers and dissolves the noises it receives. Somewhat similarly to a transformer, it converts the sound vibrations into neuron vibrations that will transmit the perceived sensations to the brain".

D. <u>Effects of Psycho-Emotive and Psycho-Sensorial Factors.</u>

Having reviewed the particular influence that vibrations and noises can exert on the genesis of operational fatigue in helicopter pilots and shown that they constitute a substantial part of the physical stress to which the pilot's organism becomes subjected during the exercise of his specific professional activity, it is not superfluous at this point to recall that, given the gradual but continuous improvement of aircraft and the growing disproportion between the service demands made by the machines and the limited possibilities offered by the human organism, we are nowadays witnessing an ever increasing incidence of psychic workload and in the piloting of an aircraft this may easily come to outweigh the actual physical workload.

This matter has already been mentioned in the introductory remarks where, treating the pathogenesis of flying fatigue, attention was drawn to the innumerable and multiform demands that the continuous nervous, psychic and emotive stresses connected with the management of the aircraft and the performance of the aerial navigation make on the delicate psychological and affective equilibrium of the pilot. It was also referred to when mention was made of the continuous psychic tension ; of the frequent and intense emotional states that are involved in evey flight, even normal and not particularly difficult ones ; of the considerable psychic commitment, involving especially the pilot's attention, called for by the continuous vigilance and the monitoring of the numerous panel instruments, and the need for instantaneously capturing and interpreting the sensorial data supplied by these instruments, which, in a perfect sensorio-motorial organization, must be immediately followed by motorial reactions that, in both time and space, are in perfect harmony with the quality and quantity of the perceptive stimuli received.

But apart from the aforementioned psychic and emotive factors, all of which have already been taken into consideration in connection with piloting any type of aircraft and any ordinary condition of operative employment, the piloting of helicopters is also subject to the intervention of other elements of a psychic nature that exert a fatiguing effect and are connected with the particular employment to which this means of transport is often put.

In fact, when the helicopter pilot is called upon to perform normal missions that are equal to those of normal aircraft of similar weight and power, ordinary line flights and the routine transport of injured people in normal conditions being cases in point, there may be no substantial difference - as far as fatigue is concerned - between helicopter pilots and the pilots of ordinary fixed-wing aircraft ; in such cases, therefore, our general knowledge of the operational fatigue of aircraft pilots retains its validity. But when the helicopter is employed as such, i.e. in operations that involve the transport or the placing of heavy suspended loads, in landing and take-off operations at high altitudes in mountainous areas, in rescue and search operations involving the over-flight of difficult and out-of-the-way terrain, or missions (no matter of what type) carried out in adverse atmospheric conditions, etc., then the effort and the fatigue involved in the helicopter pilot's workload become truly considerable and can very easily create the conditions that favour flying accidents ; indeed, accidents in this branch of aviation are unfortunately still relatively frequent.

The more delicate and complex the mission in relation to the characteristics of the ground (inhospitality of the terrain, in particular), the atmospheric conditions and the type of transport, the more the helicopter becomes exposed to the risk of an accident. In this connection one only has to think of the frequency with which the helicopter, which is considered to be an all-weather aircraft, is employed for low-level flights over inhospitable or wooded or mountainous land or over heavy seas : all of which are conditions in which possible poor weather conditions, quite apart from being in themselves potential causes of accidents (gusts of wind, electric discharges, etc.), can greatly facilitate - as a result of inadequate visibility - collisions with trees, pylons or overhead high-tension wires, hilltops or mountains, etc.

When carrying out particularly difficult and delicate missions, therefore, the subconscious of the helicopter pilot, just like and possibly even more than the subconscious of the pilot of other aircraft of greater power and speed, feels the weight of a continuous state of vigilant expectation and fear of danger, a tension that is by itself sufficient to wear out the psyche and which makes itself felt at the level of the conscious particularly in those moments when the possibly violent emotions occasioned by the sudden or unexpected arising of an internal or external emergency situation superpose themselves on the pilot's consciousness.

To this general state of expectation of danger during a flight and during the carrying out of a mission one must also add the period of time that the crews spend on the ground before taking off on a mission, often an altogether nerve-racking experience. This waiting period involves a fatigue quite independent of flying activity in the proper sense of the word, and has to be taken into due account as a factor that undoubtedly exerts a stressing and exhausting action.

Lastly, the particular type of employment reserved for helicopters involves frequent

take-offs and landings, operations that are always demanding and fatiguing, especially when they are performed in places that are far from suitable as landing grounds. In some cases the pilots also suffer from the flickering light that is caused by the rotation of the rotor blade.

Another problem to be taken into consideration is the one that arises, even during flights in traditional types of aircraft, in connection with the disorientation that the pilot may experience whenever there is a conflict between his own sensorial evaluations and the information supplied by the instruments, a conflict that may induce him - if his critical faculty has not been sufficiently trained or if it has been compromised by fatigue - to commit manoeuvering errors due to failure to correct the trim of the aircraft (or an instinctive but erroneous correction) in situations that call for manoeuvres wholly uninfluenced by the pilot's instincts.

In the case of helicopters this problem of disorientation becomes far more serious than in the case of traditional fixed-wing aircraft, because accelerations may occur simultaneously along all three of the aerodynamic axes of the vehicle : in these conditions it is possible for the pilot to experience environments and situations that are ambiguous from both the visual and the vestibular point of view.

The interaction of the sensorial informations frequently leads to conflicts in these situations, situations that can be resolved only by properly trained and updated pilots : but the need for rapidly changing from visual flying to instrumental flying, the existence of isolated light sources during the night, as well as the continuous observation of the panel instruments during certain vibration cycles, may supply sensorial reference data that are incorrect from the visual point of view and thus permit other erroneous sensorial stimuli to arise.

CONCLUSIONS.

Up to this point we have described and analyzed the nature and the entity of the various stressing and fatiguing factors that act on the organism and the psyche of pilots in general, and helicopter pilots in particular. And - always within the limits compatible with a study of this type, in which many of the judgments and views may, at least in part, be opinionable - we have analytically examined the degree of influence that the various biological, physical and psychic effects, both singly and jointly, exert on the genesis of flying fatigue.

An analytical study of this type makes it abundantly obvious that, generally speaking, the exercise of the pilot's profession is underlain by a basic situation that in the last resort permeates the whole of the pilot's activity and exerts a multiplicity of reflexes on the physique and the psyche of the pilot ; the fundamental characteristics of this situation may be summarized in the following three points :

1.- Flying involves the use of a machine that is required - unlike other machines - to respect certain aerodynamic laws, and any infraction of these laws involves an immediate risk of crash and accident. In the pilot's profession, therefore, more so than in any other human activity, life depends on the machine and its continuous efficiency, a situation that in actual practice expresses itself in the form of a permanent image of potential "vulnerability" undoubtedly present in the subconscious of each and every pilot.

2.- The pilot's activity depends a great deal on the spatial environment in which the aircraft finds itself, on the three-dimensional displaceability and the rapid translation of the aircraft and, indirectly, also on the various conditions that have repercussions on the human organism (including accelerations, acoustic and non-acoustic vibrations, equipment, sensorial stress, etc.), all of which constitute links in a chain of factors that readily explain the wealth of interferences that act on the somato-psychic equilibrium and consequently also on the performance, the adaptability and - in the long run - the fatigue of the individual.

3.- Flying does not just represent a technical or operative activity, i.e. a job, but rather - as MANGIACAPRA (1949,19) so adroitly put it - "a vital activity and an 'in toto' reaction of the ego to the environment".

On this basic substrate, which is already in itself potentially stressing and qualitatively common to all pilots, quite irrespective of their specialization and the type of aircraft they fly, there then act the interferences due to the various physical and psychic factors - each of which plays a specific and individualizing part - that we have above endeavoured to analyze and describe both in connection with aircraft in general and the use of helicopters in particular.

One might add here that it would certainly be interesting and important if it were possible to define the degree and the limits of this psychophysical workload by means of scientific methods that are technically valid and acceptable, this not least with a view to obtaining a differential assessment - in both qualitative and quantitative terms - of the various flying specializations.

In fact, numerous methods have from time to time been proposed and used for the purpose of obtaining a measure of workload by means of a quantitative evaluation of the functional modifications that fatigue can produce. As is known, these modifications may consist of : an increase of the duration and the inconstancy of the psychomotorial reaction times ; an increase of the latency time of the pupillar reflex ; a diminution of the capacity for rapid binocular fusion ; an increase of the accomodation time for near and distant vision ; a diminution of the critical frequency of fusion ("flicker fusion") (VOZZA, 1955,38 ; KRUGMAN, 1947, 16), and variations of other ophthalmic indices (ANGIBOUST and PAPIN, 1976) ; modifications of the characters and the duration (total reflex time, spinal delay, motor plaque's synaptic delay, motor and sensitive conduction velocity, Renshaw's phenomenon) of the monosynaptic spinal reflexes produced, for example, in the area of the sciatic nerve (GUALTIEROTTI, MARGARIA and SPINELLI, 1958,11) ; variations of the duration of the central nervous time of the orbicular blinking reflex under light stimulation, and the time needed for a complex mental process (total time T employed for a series of mental operations, subdivided into the reading time L, the time M needed for mental elaboration, and the writing time S : SPINELLI and CERRETELLI, 1961,34) ; diminution of the muscular force and the muscular tone ; increased instability in neuromuscular coordination ; increased loss of electrolytes through cutaneous sweating ; diminution of the volume of plasma in circulation ; variations in the urine elimination of corticosteroids (GHINOZZI, 1951,7 ; ROTONDO, 1955,27) and cathecolamine (KLEPPING and al.,1963,15, etc.); variations in the lactacidemia, the glycemia, the cholesterolemia, the ratio between alpha and beta lipoproteins, the number of the eosinophiles, and the hematocrite count ; electrocardiographic variations, and variations in the response to the Schneider test, the Flack test, and the cold pressure test ; variations in the Ruffier and Dickson index of cardiac resistance (LE ROUX, 1960,17), in anthropometric indices, etc.

Quite obviously, however, all these methods lend themselves very readily to criticism : indeed, none of the results yielded by any of these methods are capable of being interpreted in a unique manner, because the methods are indicators and measures of functional modifications that are or can be considerably influenced by a wealth of other factors, both endogenous and exogenous ones, including first and foremost the age of the subject.

If therefore, in the light of the results of a detailed analytical study, one wanted to make a comparative evaluation of the amount and the precocity of the stress and the psycho-physical workload produced by the individual stressing factors connected with flying, one would have to admit that it is extremely difficult to find a precise differential criterion that could be used to obtain a quantitative graduation of this workload.

This is not only due to the fact that the subjective element, here understood as the individuality and extreme variability of the response of a given proband to every type of stimulus, has a predominant weight in this particular activity, as indeed in every other one, but also because the nature and the entity of the reaction to any type of stimulus are in turn conditioned - as has already been shown - by numerous and extremely variable individual, environmental and circumstantial factors.

But even if reference were to be made, more or less, to the average behaviour of the average subject, one may say that if, on the one hand, the physico-psychic workload of fighter pilots is to be considered to be of considerable entity, this on account of the well known multiple stresses involved in high-speed flying, and if a far from negligible workload has to be borne by the pilots of transport, reconnaissance and rescue aircraft, etc. (for whom particularly stressing and fatiguing factors from the psychic point of view may be represented by the typical fluctuation of the state of vigilance, the boredom and the monotony connected with the long duration of the flights (on account of the great range of the aircraft), the effects of the general tiredness, and of the eyes in particular, induced by the constant fixing of the eyes on the radar screens in an attempt to identify the objects of the search, etc.), on the other hand there can be no doubt that the entity of the physical and psychic stress to which helicopter pilots are subjected is, once again, not by any means negligible.

These latter, in fact, no less than the others, are exposed to the particularly traumatic and wearing action of the various factors that - as previously described - can be identified first and foremost in the vibrations, the noises and the psycho-emotive factors connected with the multiplicity and the dangers of the uses of this modern means of air transport ; indeed, the permanent sense of potential danger that we have seen to permeate in a more or less conscious manner the subconscious of air crews is inherent in the use of helicopters and assumes particular intensity.

It is not therefore surprising to find that authoritative authors, including for example HOFFMANN, STRUBEL, RAABE and KOCK (1969,13), after carrying out interesting experimental research work aimed at determining the different operational fatigue in helicopter pilots and comparing the operational fatigue of helicopter pilots with that of pilots of other aircraft, even faster and more powerful ones, have unanimously concluded that the piloting of helicopters involves a psycho-physical workload and a fatigue that must be

considered of an entity at least equivalent (and certainly not inferior) to the workload and the fatigue to which pilots of other types of aircraft are subjected.

For the purpose of preventing this fatigue, one must obviously consider valid, just as in the case of other forms of operational fatigue in the various flying specializations, the adoption of the usual rules relating to hygiene, way of life, nourishment and, above all, work (for example, appropriate gradual adaptation of the entity and the duration of the exposure to flying stress to the age and the physical conditions of the individual, adoption of a suitable roster of service and rest periods, etc.) ; moreover, helicopter pilots must be given the benefit of a costant medical assistance and psycho-physiological check-up that will permit the immediate identification of even the early signs of fatigue and reduced physiopsychic performance.

The putting into practice of such a programme, which naturally calls for a very close and unconditional collaboration between aerospace physicians, commanders of units and the pilots themselves, would enable aerospace medicine to continue its irreplaceable work aimed at safeguarding and maintaining the psychophysical efficiency of air crews and, further, attaining an ever higher degree of flight safety as a result of the prevention of flying accidents, too many of which are still due to the human factor.

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VISUAL WORKLOAD OF THE COPILOT/NAVIGATOR DURING TERRAIN FLIGHT

by

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SUMMARY

The emphasis on aviator workload has been of primary concern to the U.S. Army aviation community since the incorporation of low altitude terrain flight techniques into the helicopter tactics repertory. Since navigation is a particularly acute problem at low altitudes, this project examined the visual workload of the navigator/copilot during terrain flight (nap-of-the-earth, contour and low level) in a UH-1H helicopter. The navigator's task was to: (1) perform a map study of the prescribed course, (2) direct the pilot during the flight as to the direction of flight, altitude and airspeed desired to traverse the course, and (3) identify hover points and checkpoints along the route which were given to the navigator in terms of six digit grid coordinates. Visual performance was measured via a modified NAC Eye Mark Recorder used in conjunction with a LO-CAM high speed camera. This technique provided the means to objectively record and analyze the navigator's visual performance through the examination of: (1) visual time inside the cockpit on flight and engine instruments, (2) time inside the cockpit on the map or other navigation aids, and (3) time outside the cockpit in various windscreen sectors.

A visual free time task (Strother, 1973) was utilized to determine the amount of visual time the navigator had available, during flight over the prescribed course, for a nonflight related task. The data indicate that the navigator's normal workload was demanding; the visual free time task was utilized only 3% of the total time. The data also indicate that the duty of navigating required 92.2% of the copilot's total visual time while the engine and flight instruments were utilized only 4% of the time. These data are discussed in relation to the copilot's specified duties.

INTRODUCTION

The tactical requirement to conduct Army helicopter operations close to the earth has presented formidable navigation problems to Army aviators. Aviators forced to maintain aircraft masking while proceeding to enemy contact points, landing zones or MEDEVAC pick-up points, have the difficult task of determining their position and navigating to and from these points with little aid in terms of salient landmarks and terrain features. Further, this problem is considerably increased with the need for round-the-clock all weather operations.

Pilot and copilot workload has increased significantly with utilization of tactical terrain flight techniques. The increased workload experienced by the Army aircrew is due, in part, to the relative perceptual speeds at which terrain is traversed and the subsequent short periods of time that navigational cues remain in the visual field. Terrain flight consists of nap-of-the-earth (NOE), contour and low level flight profiles. These flight profiles have been defined as:

NOE. Flight as close to the earth's surface as vegetation or obstacles will permit, while generally following the contours of the earth. Airspeed and altitude are varied as influenced by the terrain, weather, and enemy situation. The pilot preplans a broad corridor of operation based on known terrain features which has a longitudinal axis pointing toward his objective. In flight, the pilot uses a weaving and devious route within his planned corridor while remaining oriented along his general axis of movement in order to take maximum advantage of the cover and concealment afforded by terrain, vegetation and man-made features. By gaining cover and concealment from enemy detection, observation and fire power, nap-of-the-earth flight exploits surprise and allows for evasive actions.

Contour. Flight of low altitude conforming generally and in close proximity to the contours of the earth. This type of flight takes advantage of available cover and concealment in order to avoid observation or detection of the aircraft and/or its points of departure and landing. It is characterized by a varying airspeed and a varying altitude as vegetation and obstacles dictate.

Low Level. Flight conducted at a selected altitude at which detection or observation of the aircraft is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant airspeed and altitude. This method is best adapted to flights conducted over distances or periods of time.

The additional workload imposed on the aircrew during terrain flight has necessitated a division of duties. The pilot's primary responsibility during terrain flight has been the demanding task of maintaining clearance of the aircraft from all man-made and terrain obstacles as well as directing the aircraft over the desired route. The copilot, therefore, has assumed duties which entail, among other things: (1) monitoring the map and navigation instruments as well as the terrain in an attempt to locate the significant navigational cues needed for maintaining the correct flight path, (2) monitoring the helicopter engine instruments and other flight instruments, (3) tuning the radios, (4) orally providing navigational information to the pilot that will allow him to maintain the appropriate flight path, and (5) helping the pilot locate and avoid potentially hazardous terrain obstacles.

Workload has been defined as "the sum of the task demands which can be clearly specified, plus the operator's response (and effort) to satisfy these demands" (Gerathewohl, 1976). Pilot or navigator workload can be evaluated directly in terms of activity or effort on a primary task or indirectly by

examining reserve capacity or time available for the performance of a secondary task (Gerathewohl, 1976; and O'Donnell, 1976). One specific approach for workload examination is in terms of visual demands upon the navigator (in this study) and the distribution of his visual time.

Previous studies (Senders, 1973; Jones, Milton, and Fitts, 1946) have suggested that "frequency of eye fixation on any given instrument is an indication of the relative importance of that instrument. The length of the fixations, on the contrary, may more properly be considered as an indication of the relative difficulty of checking and interpreting particular instruments."

Recent research (Strother, 1974) has identified the visual workload problems encountered by the pilot during straight and level flight at varying altitudes. This research demonstrated that "the duration and frequency of visual scan intervals change between NOE and 300 feet of altitude and that below 100 feet, any demands on the pilot's time can only be of the simplest type unless he is unburdened from his visual tasks."

Since the duties and responsibilities of the copilot have increased a great deal in a very short time frame, the objective of the current research project was to examine the existing visual workload (oculomotor performance) of the navigator/copilot during terrain flight.

METHOD

Subjects. Subjects participating in the investigation were ten recent graduates of the U.S. Army Initial Entry Rotary Wing flight training program of instruction at Fort Rucker, Alabama. These pilots had recent training in navigation during terrain flight and an average of 287 total flight hours. All participants had at least 115 hours of flight experience in the UH-1H helicopter.

Apparatus. Oculomotor performance was recorded via a modified NAC Eye Mark Recorder used in conjunction with a 16mm LOCAM high speed motion picture camera. Through the utilization of the NAC Eye Mark Recorder, the aviator's viewing point was detected by means of an illuminated reticle reflected off the cornea of the eye. The optically focused reticle, reflected from the cornea, was superimposed upon a primary image with a field of view of 43.5^{o} vertical and 60^{o} horizontal. Figures 1 and 2 show a subject aviator wearing the modified Eye Mark Recorder. One can also see the fiber optic bundle connecting the Eye Mark Recorder to the LOCAM 16mm camera, which is attached to the pilot's seat. A detailed description of the Eye Mark Recorder and scoring techniques utilized can be found in USAARL Report 74-7 and Simmons (1977). The test vehicle was a JUH-1H helicopter.

Figure 1. Aviator Wearing the Modified NAC Eye Mark Recorder

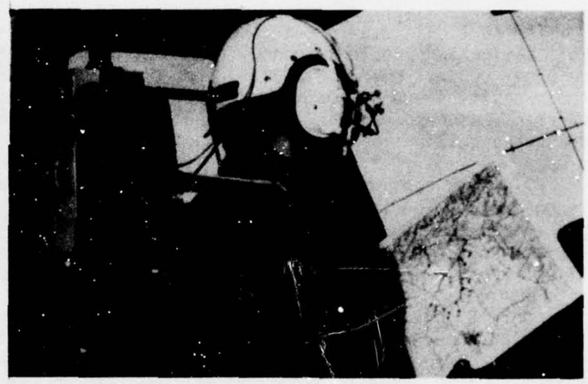


Figure 2. Copilot Prepared for Flight in the UH-1H Helicopter

The visual free time task utilized consisted of a 5X7 card containing random monosyllabic words (reference Figure 3). The card was bordered in black and had a white background with black letters. The card was sprayed with a glare reducing compound and mounted on the UH-1H instrument panel directly below the vertical velocity indicator. The average distance from the subject's eyes to the visual free time task card was 87 centimeters (reference Table 1 for cockpit measurement data).

The maps utilized were standard 1:50,000 scale, with white background, of the Geneva (Stock No. V744X38463) and Hartford (Stock No. V744X38462), Alabama area. A 255 square kilometer portion of the maps around the Highfalls stagefield was prepared for use by the participants.

The navigation course, approximately 19 kilometers long, was marked on the map (reference Figure 4). The participants were given six digit grid coordinates of five phase points/checkpoints plus the initial point (IP) of the navigation course. These points were to be identified on the map by the subject during his map study and reported upon passage during flight over the course. The subjects were also given a list containing six digit grid coordinates of five hover points located along the navigation course. These points were utilized to represent landing points, such as equipment or personnel pick up points, in an operational setting.

Procedure. The participants were first given a briefing concerning the general nature of the project and their role in the project. The subjects were provided the map similar to the one shown in Figure 4 (excluding the location of the checkpoints and hover points) and the list of phase/checkpoints and hover points. The participants were told that they were to act as navigator or copilot and that a USAARL pilot would act as first pilot or aircraft commander during the flight. The participants were able to perform a map study for the rest of that day and reported to the aircraft the next day prepared to fly.

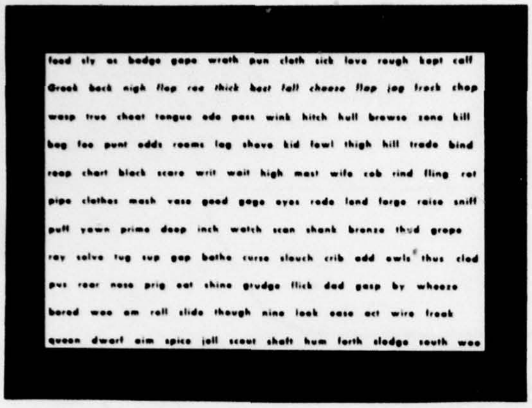


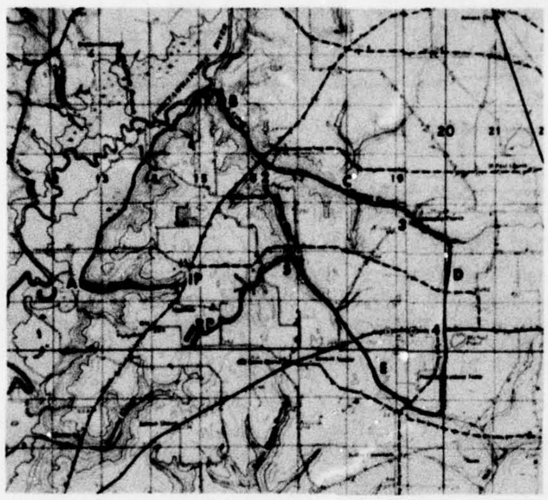
Figure 3. Visual Free Time Task

TABLE 1

COCKPIT MEASUREMENT DATA

	Eye to Floor	Eye to Magnetic Comp.	Eye to VFT Task
Subject One	101.60	68.58	86.36
Subject Two	107.95	81.28	88.90
Subject Three	106.68	71.12	88.90
Subject Four	108.59	76.20	91.44
Subject Five	104.14	76.20	83.82
Subject Six	109.22	85.09	93.98
Subject Seven	100.33	73.66	83.82
Subject Eight	113.03	83.82	88.90
Subject Nine	107.95	82.55	86.36
Subject Ten	110.49	77.47	95.25
Mean	106.99	77.59	88.77

*Unit of measurement - centimeters.



NAVIGATION COURSE____ SCALE 1:50,000

IP-INITIAL POINT CONTOUR INTERVAL-20 FEET

RP-RELEASE POINT 1,2,3,4,5-CHECK POINTS

A,B,C,D,E-HOVER POINTS

Figure 4. Navigation Course Utilized in the Investigation

Immediately before flight, the subjects were again informed that they were to act as copilot/navigator and to perform all duties associated with that position. The UH-1H Tactics Flight Training Guide (March 1975), which identifies the pilot and copilot's in-flight duties, was given to the subjects to refresh their memory as to the exact functions expected of them during the flight. The participants were told that their responsibility for the flight was to direct the pilot to fly along the course identified on the maps provided. They were responsible for keeping the pilot informed so that he could fly the aircraft as close to the course as possible.

The following VFT task instructions, which are similar to the Strother (1974) study, were also given to the subjects: "During the course of the flight, when you feel that it is not necessary to look inside or outside the helicopter in performance of your navigation duties, read the words located on the card mounted on the instrument panel. Start reading at any word and it is not necessary to pick up where you stopped before. Read aloud as many words as you feel you have time for and then stop reading and return to your normal duties."

The NAC Eye Mark Recorder was fitted and calibrated on the subject inside the USAARL research facility followed by a recalibration of the device after the subject was seated and prepared for flight in the left front seat of the UH-1H aircraft. From takeoff to completion of the course, subjects were completely responsible for the flight path of the helicopter with the USAARL pilot changing heading, airspeed and altitude in response to their directions. The subjects were instructed to report the passage of the five phase/checkpoints. Subjects were also responsible for identifying the five hover points and directing the pilots to hover at these points.

RESULTS AND DISCUSSION

For scoring purposes, the visual performance data were divided into ten visual areas of interest. These areas are schematically presented in Figure 5. The copilot's instrument panel was divided into functional groups of instruments, e.g., navigation instruments (the RMI and magnetic compass) engine instruments, etc. The copilot's windscreen was originally divided into four quadrants, but these areas were consolidated into one visual area for data interpretation purposes.

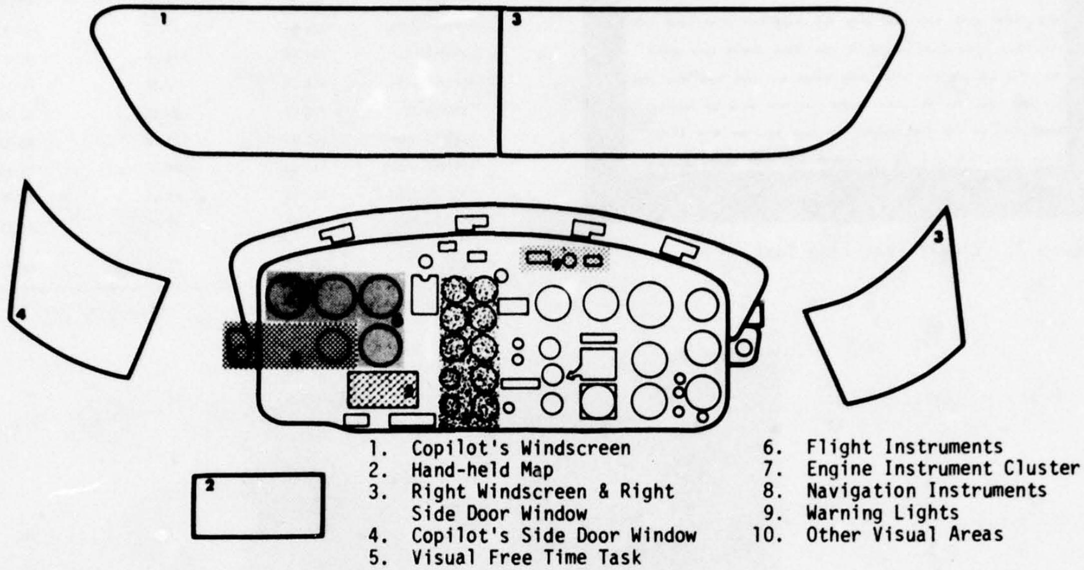


Figure 5. Schematic of UH-1 Visual Areas

Tables 2 through 7 show the summary of the visual data for each of the segments in the navigation course for all subjects whose data were scorable. Segments of data were lost on some subjects as a function of camera malfunctions and film exposure problems due to the fact that the NAC Eye Mark Recorder system does not have an automatic T-stop adjustment capability. However, the data remaining reflect accurately the visual performance exhibited during navigation.

TABLE 2

VISUAL PERFORMANCE SUMMARY DATA FOR SEGMENT ONE OF THE NAVIGATION COURSE IP TO HOVER POINT A

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	792.28	0.524	14.04	2.23
Handheld Map	424.81	0.281	10.26	1.63
Right Windscreen & Right Side Door Window	110.19	0.073	3.48	1.24
Copilot's Side Door Window	106.21	0.070	2.58	1.61
Visual Free Time Task	14.06	0.009	0.24	2.01
Flight Instruments	18.72	0.012	0.72	0.99
Engine Instrument Cluster	11.61	0.007	0.54	0.77
Navigation Instruments	15.61	0.010	0.90	0.65
Warning Lights	9.31	0.006	0.30	1.03
Other Visual Areas	10.33	.006	0.36	1.03

TABLE 3

VISUAL PERFORMANCE SUMMARY DATA FOR SEGMENT TWO OF THE NAVIGATION COURSE HOVER POINT A TO HOVER POINT B

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	1073.38	0.490	12.96	2.27
Handheld Map	752.04	0.344	11.16	1.84
Right Windscreen & Right Side Door Window	103.54	0.047	2.58	1.07
Copilot's Side Door Window	87.57	0.040	1.68	1.41
Visual Free Time Task	42.95	0.019	0.24	4.29
Flight Instruments	64.95	0.029	0.36	1.38
Engine Instrument Cluster	37.90	0.017	0.72	1.40
Navigation Instruments	11.41	0.005	0.36	0.81
Warning Lights	4.82	0.002	0.12	0.96
Other Visual Areas	4.52	0.002	0.18	0.56

Some of the key items of interest in Tables 2 through 7 are the mean dwell time figures representing the average period of visual contact with the area and percentage of total time of the segment spent in each of the visual areas.

TABLE 4

VISUAL PERFORMANCE SUMMARY DATA FOR
SEGMENT THREE OF THE NAVIGATION COURSE
HOVER POINT B TO HOVER POINT C

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	396.31	0.436	12.00	2.18
Handheld Map	302.51	0.332	9.36	2.13
Right Windscreen & Right Side Door Window	24.13	0.026	1.86	0.83
Copilot's Side Door Window	96.62	0.106	4.02	1.58
Visual Free Time Task	30.29	0.033	0.36	5.04
Flight Instruments	27.96	0.030	0.72	2.54
Engine Instrument Cluster	3.20	0.003	0.30	0.64
Navigation Instruments	5.83	0.006	0.48	0.72
Warning Lights	17.05	0.018	0.42	2.43
Other Visual Areas	4.56	0.005	0.00	0.31

TABLE 5

VISUAL PERFORMANCE SUMMARY DATA FOR
SEGMENT FOUR OF THE NAVIGATION COURSE
HOVER POINT C TO HOVER POINT D

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	798.08	0.452	11.40	2.38
Handheld Map	656.30	0.372	9.90	2.25
Right Windscreen & Right Side Door Window	74.97	0.042	2.10	1.19
Copilot's Side Door Window	77.03	0.043	1.62	1.60
Visual Free Time Task	87.47	0.049	0.40	7.28
Flight Instruments	18.46	0.010	0.60	1.02
Engine Instrument Cluster	19.87	0.011	0.54	1.24
Navigation Instruments	11.31	0.006	0.48	0.75
Warning Lights	1.91	0.001	0.10	0.63
Other Visual Areas	16.44	0.009	0.48	1.09

TABLE 6

VISUAL PERFORMANCE SUMMARY DATA FOR
SEGMENT FIVE OF THE NAVIGATION COURSE
HOVER POINT D TO HOVER POINT E

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	803.22	0.449	13.50	1.99
Handheld Map	659.28	0.368	10.98	2.00
Right Windscreen & Right Side Door Window	94.66	0.052	3.06	1.02
Copilot's Side Door Window	42.88	0.023	1.02	1.38
Visual Free Time Task	67.83	0.037	0.63	3.57
Flight Instruments	37.95	0.021	1.02	1.22
Engine Instrument Cluster	38.10	0.021	1.20	1.02
Navigation Instruments	24.54	0.013	0.90	0.87
Warning Lights	10.08	0.005	0.18	1.68
Other Visual Areas	10.25	0.005	0.42	0.78

TABLE 7

VISUAL PERFORMANCE SUMMARY DATA FOR
SEGMENT SIX OF THE NAVIGATION COURSE
HOVER POINT E TO HIGHFALLS STAGEFIELD (RP)

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	882.15	0.445	13.44	1.98
Handheld Map	753.68	0.380	11.22	2.03
Right Windscreen & Right Side Door Window	95.74	0.048	3.24	0.88
Copilot's Side Door Window	62.37	0.031	1.68	1.11
Visual Free Time Task	65.95	0.033	0.72	2.74
Flight Instruments	19.89	0.010	0.60	0.99
Engine Instrument Cluster	59.53	0.030	1.02	1.70
Navigation Instruments	11.06	0.005	0.42	0.73
Warning Lights	6.96	0.003	0.30	0.63
Other Visual Areas	21.90	0.011	0.54	1.21

Figure 6 provides summary data for all six flight segments in terms of the percentage of total visual time spent in each of the ten visual areas. The shaded area includes all mean data points for each of the six flight segments. The consistency between flight segments is particularly noteworthy. These data indicate very little variability in percent of time each of the visual areas were utilized over the entire navigation course. Though the terrain traversed did vary to some degree over the course, the information demanded from each of the visual areas remained relatively constant. That is, visual cues needed for navigation were primarily obtained from terrain viewed through the copilot's windscreen with frequent reference to the handheld map.

It is noteworthy that the visual cues necessary for navigation were evidently present primarily in the area viewed through the copilot's windscreen. This fact is pointed out in the data presented in Figure 6 and Table 8 which contains the summary data for all six flight segments combined. The navigators spent 46.8% of the total visual time during the flight obtaining information through the left windscreen compared to: (1) 5% of the time viewing the terrain through the right windscreen and right door window, and (2) 4.9% of the time searching for navigation information through the left door window.

The magnitude of the demand for visual information can be seen in Figure 7, which reflects summary data for all six flight segments combined in terms of the number of exits per minute for each of the visual areas. Interpretation of these data should be made in light of Senders' statement that the frequency of eye fixations in a visual area reflects the relative importance of that area. Thus, two areas, copilot's windscreen and the handheld map, far outweigh all others in terms of frequency of demand of visual information. These data point to the copilot's primary duty of navigating and seeking information in the terrain which corresponds to that depicted on the map. Following these two high visual use areas are two other windscreen or window areas: (1) right windscreen and right side door window, and (2) copilot's left side window. The percentage of time in each visual area also shows the same order of utilization: (1) copilot's windscreen, (2) handheld map, (3) right windscreen and right side door window, and (4) copilot's left side door window. Again, the total visual contact for these areas, for all flight segments, (reference Table 8) represents 91.4% of the time in flight. More specifically, 56.5% of the time was used by the aviators to obtain navigation cues from outside the cockpit and an additional 34.9% of the flight time was spent obtaining information from the handheld map.

TABLE 8

VISUAL PERFORMANCE SUMMARY DATA
REPRESENTING ALL SIX FLIGHT SEGMENTS

Visual Area	Total Time in Seconds	Percent of Total Time	Total Number of Exits/Min.	Mean Time in Area
Copilot's Windscreen	4744.35	0.468	12.82	2.191
Handheld Map	3540.60	0.349	10.64	1.197
Right Windscreen & Right Side Door Window	508.20	0.050	2.81	1.069
Copilot's Side Door Window	472.85	0.047	1.96	1.428
Visual Free Time Task	308.66	0.030	0.44	4.115
Flight Instruments	187.95	0.018	0.91	1.212
Engine Instrument Cluster	170.16	0.017	0.78	1.289
Navigation Instruments	79.80	0.008	0.58	0.806
Warning Lights	50.16	0.005	0.24	1.223
Other Visual Areas	68.50	0.007	0.40	1.007

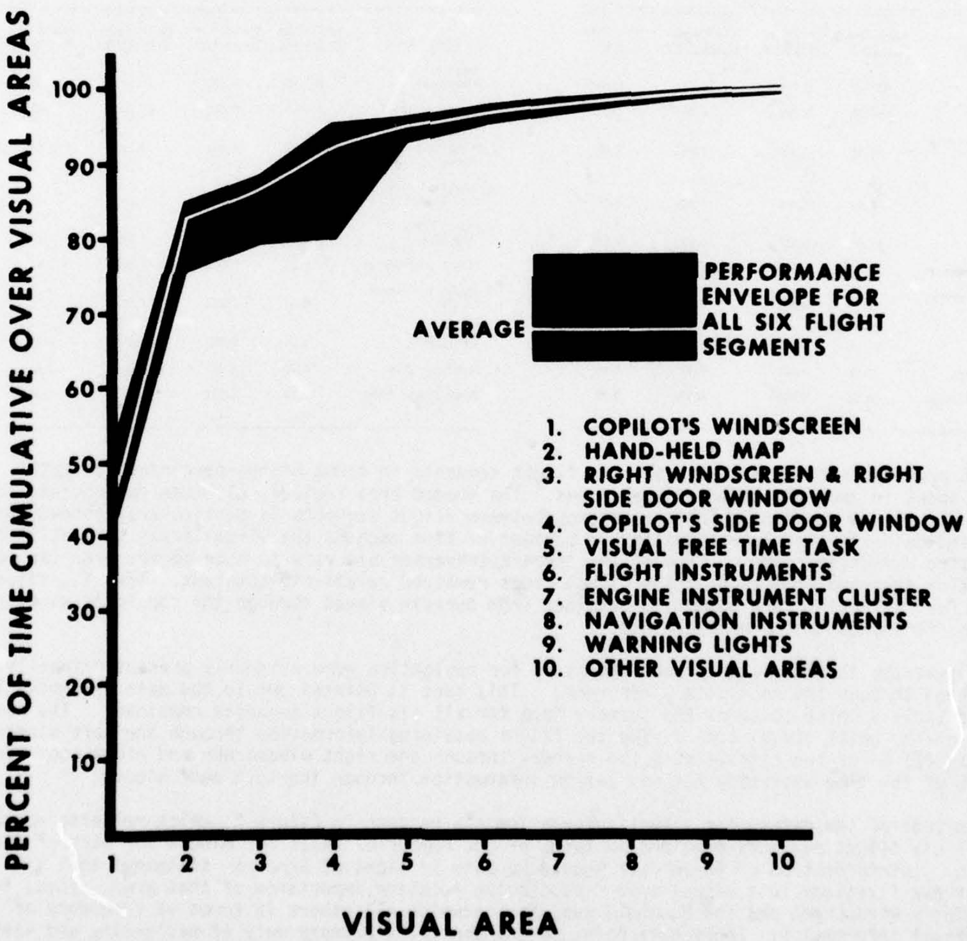


Figure 6. Percentage of Time Across Visual Areas*

Traditionally, heading reference obtained from the RMI and magnetic compass has been critical for successful navigation at higher altitudes. However, the summary data (reference Table 8 and Figures 6, 7 and 8), indicate that the magnetic compass and RMI are used very infrequently and for the shortest mean dwell time. When the percentage of time the RMI and magnetic compass were used is added to the

previously mentioned time spent outside the cockpit and time spent on the map, a total of 92.2% of the visual time is accounted for by the performance of the basic duty of navigation.

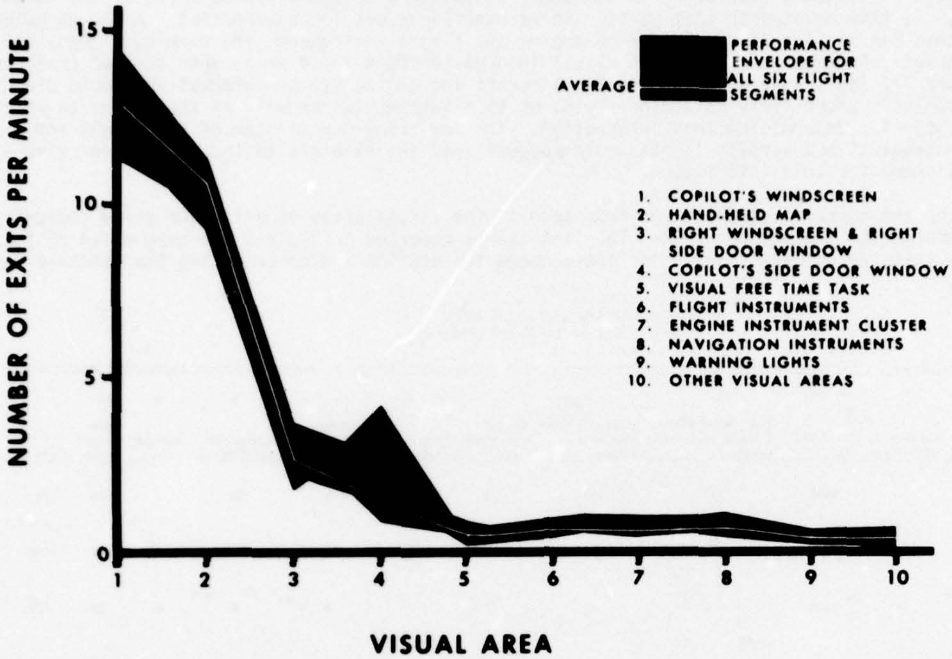


Figure 7. Exits Per Minute Across Visual Areas

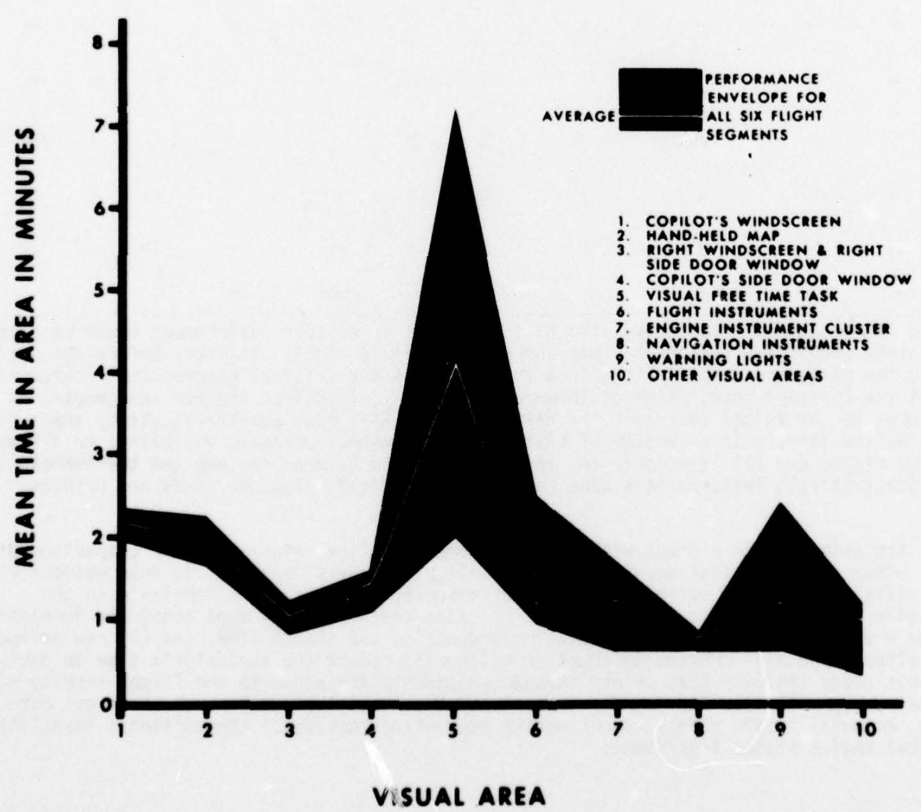


Figure 8. Mean Time in Each Visual Area

It should be noted that it is the pilot's duty to "perform the pretakeoff and landing checks prior to all takeoffs and approaches except when flying a position in formation other than lead." Excluding these checks, the copilot's specified duty, "monitor engine and flight instruments and advise pilot as required," commanded only 4.0% of the copilot's visual time over all the flight segments of the navigation

course. In scoring, the master caution light was not included in warning light visual area. A very small percentage of the time attributed to the other visual areas category could have been spent on the master caution light. However, time spent in the other visual area category was only .7% of the total time; therefore, the time devoted to this particular warning light was inconsequential. Although guidelines are not established for the frequency of scan of engine and flight instruments and warning lights, one would assume a greater frequency of demand of visual information from these areas than existed (reference Table 8 and Figure 7). The frequency of demand for aircraft and engine status information should directly relate to the copilot's uncertainty about the status of this information as well as the degree to which he feels responsible for determining this information. The low frequency of scan of the flight and engine status instruments and warning lights would suggest that the aviators tested did not perceive a critical personal need for this information.

Link values or the number of transitions from each of the visual areas to all other areas indicates the copilot's information seeking behavior. The link values reported in Table 9 are supportive of the previous data in that the primary transitions are between the copilot's windscreen and the handheld map.

TABLE 9

LINK VALUES BETWEEN VISUAL AREAS
TOTALED ACROSS ALL SIX FLIGHT SEGMENTS

	1 Copilot's Windscreen	2 Hand-Held Map	3 Right Windscreen & Right Side Door Window	4 Copilot's Left Side Door Window	5 Visual Free Time Task	6 Flight Instruments	7 Engine Instrument Cluster	8 Navigation Instruments	9 Warning Lights	10 Other Visual Areas	Total
1 Copilot's Windscreen	-	1440	331	198	30	58	55	28	7	16	2163
2 Hand-Held Map	1463	-	108	110	12	43	17	27	9	9	1798
3 Right Windscreen & Right Side Door Window	253	165	-	12	2	3	9	4	6	22	476
4 Copilot's Left Side Door Window	207	106	1	-	-	2	3	-	1	2	322
5 Visual Free Time Task	38	11	5	-	-	7	9	7	1	1	79
6 Flight Instruments	66	22	4	4	7	-	13	28	1	1	146
7 Engine Instrument Cluster	58	21	2	7	14	13	-	4	15	10	144
8 Navigation Instruments	47	17	4	-	5	24	1	-	1	2	101
9 Warning Lights	12	2	2	-	2	2	14	-	-	5	39
10 Other Visual Areas	21	13	18	-	3	3	11	1	-	-	70
Total	2165	1797	475	331	75	155	132	99	41	68	

The primary act of navigation in a rotary wing NOE, low level or contour environment could be described as a feature or pattern comparison between the map and the terrain in sight. However, before the pattern matching can occur, the navigator must first perform a search task for critical geographical features. Navigation requires the constant integration of information deemed critical on the map and comparing this array of features to the actual terrain. The navigator's task is made more difficult by the fact that he must (1) view the terrain in a variety of states, e.g., seasonal changes, visibility or illumination differences, day and night; and (2) compensate for the discrepancies between the map and the terrain in areas where significant terrain features have been changed, e.g., fields cleared, roads and bridges added, etc.

In conclusion, the data from this study will provide useful baseline information for comparison with the performance of other aircrew duties or missions. As well, it is very important to note objectively the copilot's priorities in carrying out his primary and secondary subtasks. The imbalance in the copilot's distribution of visual time across subtasks indicates that: (1) new maps should be developed that will allow the navigator to reduce his information processing and search time, and (2) new navigation aids should be developed that will provide information which will reduce the navigator's time on navigation tasks. Data from this study indicate that unless these developments are added to the flight inventory, the copilot will have a very limited opportunity to perform other in-flight tasks such as target detection and identification. As well, flight safety is currently compromised because of the copilot's inability to attend to critical engine status instruments.

DISCLAIMER

The findings in this report are not to be considered as an official Department of the Army position unless so designated by other authorized documents.

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IN-FLIGHT RECORDING OF HELICOPTER PILOT ACTIVITY

by

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SUMMARY

Head and hand activity patterns have been established for UK Army and Air Force helicopter pilots under a variety of operational flight conditions using a cine filming technique. A fully portable cine camera fitted with a 'fish eye' or wide angle lens has been used to record pilots' head and hand movements in 6 different helicopters and 2 fixed wing aircraft types during nap-of-the-earth, low level and other flight phases.

Apart from highlighting problem areas in the cockpit, the film records show that activity patterns depend more upon the flight profile than upon the helicopter type or the individual pilot. Subsequent film analysis has shown that the pilot work-load tends to increase with decreasing height above the ground. During nap-of-the-earth tactical flying, a pilot may spend over a third of the time looking inside the cockpit at maps, instruments and radios. This is precisely the time when he needs to spend the maximum time looking outside to detect and evade potential hazards such as wires, trees, enemy positions etc. Reasons for the apparently paradoxical behaviour and the effect upon pilot work-load are discussed.

Typical pilot activity patterns are presented, together with an example of how poor cockpit design can obviously increase work-load and reduce efficiency.

ACTIVITY RECORDING EQUIPMENT

Some problem areas can often be highlighted by studying pilot activity patterns during normal flight operations. The simplest way to do this is to sit alongside the pilot and note down his actions as the flight progresses, but this technique has a number of disadvantages. First, the Observer is not always aware or may not understand what the pilot is doing. If several events occur simultaneously or in quick succession, it is unlikely that all will be noted by the Observer. Perhaps the most important disadvantage of all is, that when the pilot notices that the Observer is making notes, he will, subconsciously, change his activity patterns. A far better method, which overcomes most of these shortcomings, is to use a cine camera to record cockpit events. This has the advantage that the film can be viewed later, analysed and re-analysed at leisure in a warm, quiet, motion free laboratory.

Although this cine recording technique is well established in the work study area, it has not been used often in aviation. (1). This is due, possibly, to the difficulty in mounting a cine camera in a cockpit in such a way that an adequate field of view can be covered. One approach, in which this difficulty can be overcome is by replacing the cine cameras conventional lens with a wide angle or 'fish eye' lens which gives a field of view of over 180°. This is wide enough to enable both head and hand movements of the pilot to be recorded simultaneously. A frame from a 16 mm cine film is shown in Figure 1. Although the picture taken through a fish eye lens is somewhat distorted, the worst distortion is around the edges. The centre region of the picture is only slightly out of shape and can be interpreted easily.

By holding the camera in the hand (see Figure 2) it can be re-aligned instantly to record any unexpected event which might be outside the normal range of pilot movements. Any lack of positioning accuracy which might be present with a hand-held camera is compensated for by the wide angle lens, which is not at all critical in alignment requirements and needs only to be pointed in the general direction of the pilot. Another advantage of this camera, which also has its own power supply, is that it can be carried aboard an aircraft by the Observer and used immediately. A conventional rigidly mounted camera would require time for airframe mounting brackets to be designed, fabricated, approved and installed. These modifications would effectively limit its use to one or two specific aircraft. The hand-held fish eye cine camera has no such restrictions.

PILOT ACTIVITY PATTERNS

When a record has been made of pilot activity during flight, the film is processed and then analysed frame by frame. Multiple activity charts of head and hand activity can then be plotted and times, etc, for each activity can be calculated. (See Figures 3 to 6). By recording the activity of different pilots in the same aircraft, and of the same pilots in different aircraft, while performing a variety of tasks, a set of activity patterns can gradually be built up. Figure 3 shows a pilot's head activity pattern during low level flight in a Wessex at about 100 ft above ground level and at an air speed (IAS) of 90 knots. This viewing pattern is typical of a helicopter pilot flying at this height and speed. The pattern is characterised by the majority of time spent looking to the front in long looks of between 10 and 15 seconds, separated by shorter glances of about a second or so to either side or inside the cockpit to instruments.

When the helicopter pilot flies closer to the ground in 'nap-of-the-earth' (NOE) flight, the pilot's viewing pattern will change to that illustrated in Figure 4. (Illustrations of what is meant by low level and NOE flight are shown in Figure 7.) NOE pilot activity is typified by a rapid succession of short glances or swift hand movements of a few seconds or less. Less time is spent looking to the front and more time is required to look inside at instruments, radios and maps. During NOE flight the pilot is flying not only lower but in between or around trees, pylons, buildings and other hazards. He cannot afford to look for more than a few seconds in any one direction. Because he is flying lower, he cannot see so far ahead. His horizon at NOE height may be only a few tens of yards away (see Figure 8) whereas at 500 ft height he may be able to see for miles. (See Figure 9.) Consequently at low level he needs to spend more time navigating by trying to relate his limited view ahead or to the side with his expected position on the map.

The NOE pilot must constantly check his instruments to detect system changes before system failures occur. For example, in NOE flight there is little time to take remedial action once an engine has failed.

Badly installed radios and other equipment can severely disrupt a pilot's efficiency, especially during NOE flight. The frame from the fish eye cine film in Figure 1 shows a pilot trying to tune a radio which has been installed behind his and his co-pilot's seat. To do this a pilot has to remove his left hand from the collective lever and hold it under his knee. He then has to turn round and face rearwards to see the frequency of the dial. The radio installation shown is still further complicated by being a combination of 3 separate items of equipment. One item of which is mounted upwards, the next on its side and the third upside down. One wonders if the equipment designer thought by this means he would have a 1 in 3 chance of getting something right!

Figures 5 and 6 illustrate how overt activity patterns change with flying task. In the case of Figure 5 the Scout pilot is wearing chemical defence (CD) clothing, including a CD hood and S6 respirator. The respirator, in particular, restricts the pilot's vision and is generally very uncomfortable to wear with normal flying clothing. At the start of the sortie during hover taxi out on to an airfield, the pilot is not unduly uncomfortable or stressed. This is reflected by the activity pattern in Figure 5 which resembles that of the Wessex pilot at low level in Figure 3.

This relatively relaxed pattern changes when the CD Scout pilot begins to fly at low level. He is now beginning to work far harder and is in some discomfort. This results in a viewing activity pattern much more similar to the normally clothed Scout pilots' pattern during NOE flight, shown in Figure 4.

Halfway through the sortie, the pilot removes his hood and respirator and, after a short rest, returns at low level to the airfield. During this return stage of the flight his activity pattern (see Figure 6) returns to the more leisurely pattern exhibited by the Wessex pilot at low level, shown in Figure 3.

Other phases of helicopter flight have been investigated by this method of cine film analysis. (2). Figure 10 shows how frequency distributions of time of glance by a Puma pilot vary with different phases of flight. These histograms show that when a pilot is performing more exacting tasks near to the ground, of descent or hover in a wooded clearing, he cannot afford to look inside the cockpit for more than a second or so at a time. By comparison, during cruise, when he is well clear of the ground obstructions, he can look more often and for longer periods inside the cockpit. In other words, when flying close to the ground, the helicopter pilot, or for that matter any other pilot, needs to keep a constant look-out of the cockpit to see wires, trees, buildings and other dangers in time to take avoiding action. Any time spent looking inside is potentially hazardous. At greater heights above the ground the risk of a collision is much reduced and the pilot can afford to spend both more and longer periods looking within his cockpit.

CONCLUSIONS

Although the cine film analysis technique outlined here provides a far from comprehensive record of helicopter pilot activity, it does reveal a number of interesting points and indicates some problem areas which might profit from further study.

Head activity patterns of well trained pilots tend to be a function of task and to a lesser extent of the individual pilot, type of helicopter, or equipment fit. With existing small to medium sized helicopters, if a pilot has to fly at very low level due to tactical or other reasons he might spend up to a third of his time looking inside the cockpit. He must therefore be provided with improved navigational and radio aids and with engine, fuel and transmission systems having greater reliability. In addition every effort must be made to give the helicopter pilot improved protective clothing, seating, controls, displays, cockpit vision and cabin environment.

ACKNOWLEDGEMENTS

The author would like to thank pilots from the Army Air Corps, the Royal Air Force and the Royal Navy and for staff of the Human Engineering Division at Farnborough for their willing assistance and without whose help this work would not have been possible.

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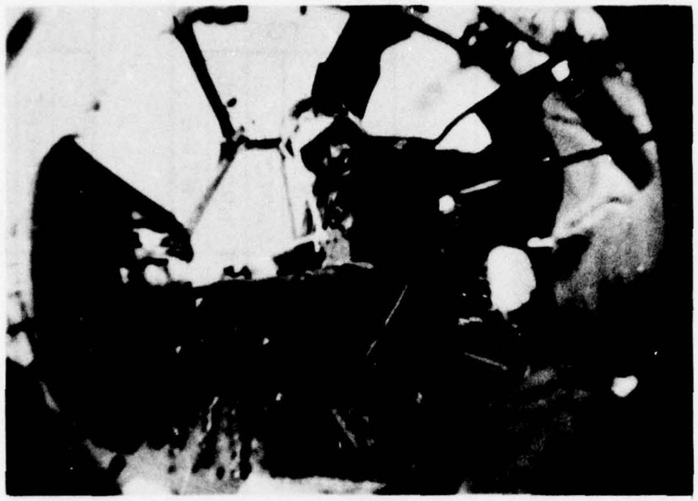

Fig 1 Helicopter pilot operating a badly positioned radio during "Nap of the Earth" flight.

Fig 2 Observer filming pilot with "Fish-eye" cine camera.

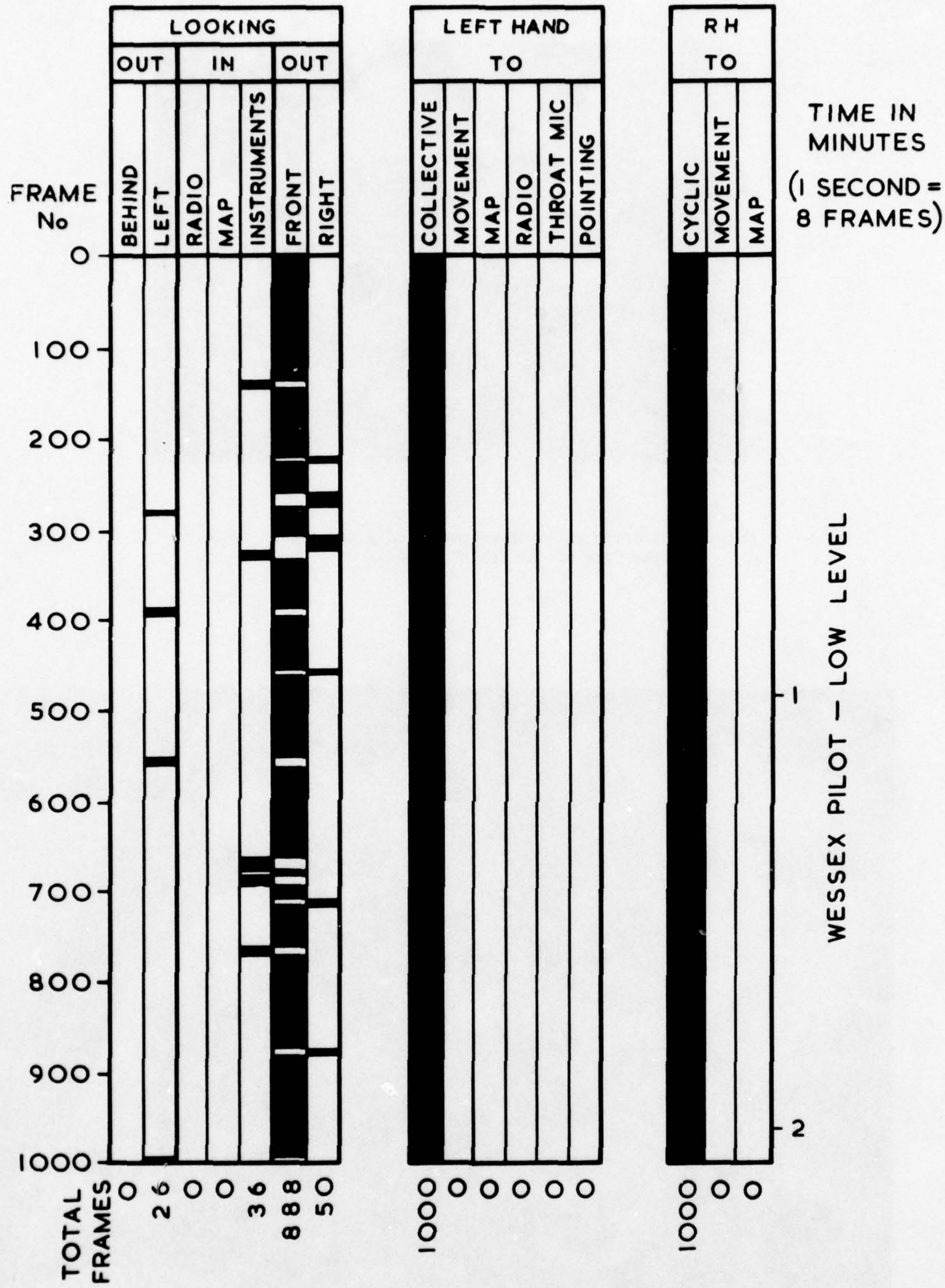

FIG. 3 HEAD AND HAND ACTIVITY OF WESSEX PILOT IN NORMAL FLYING CLOTHING DURING LOW LEVEL FLIGHT

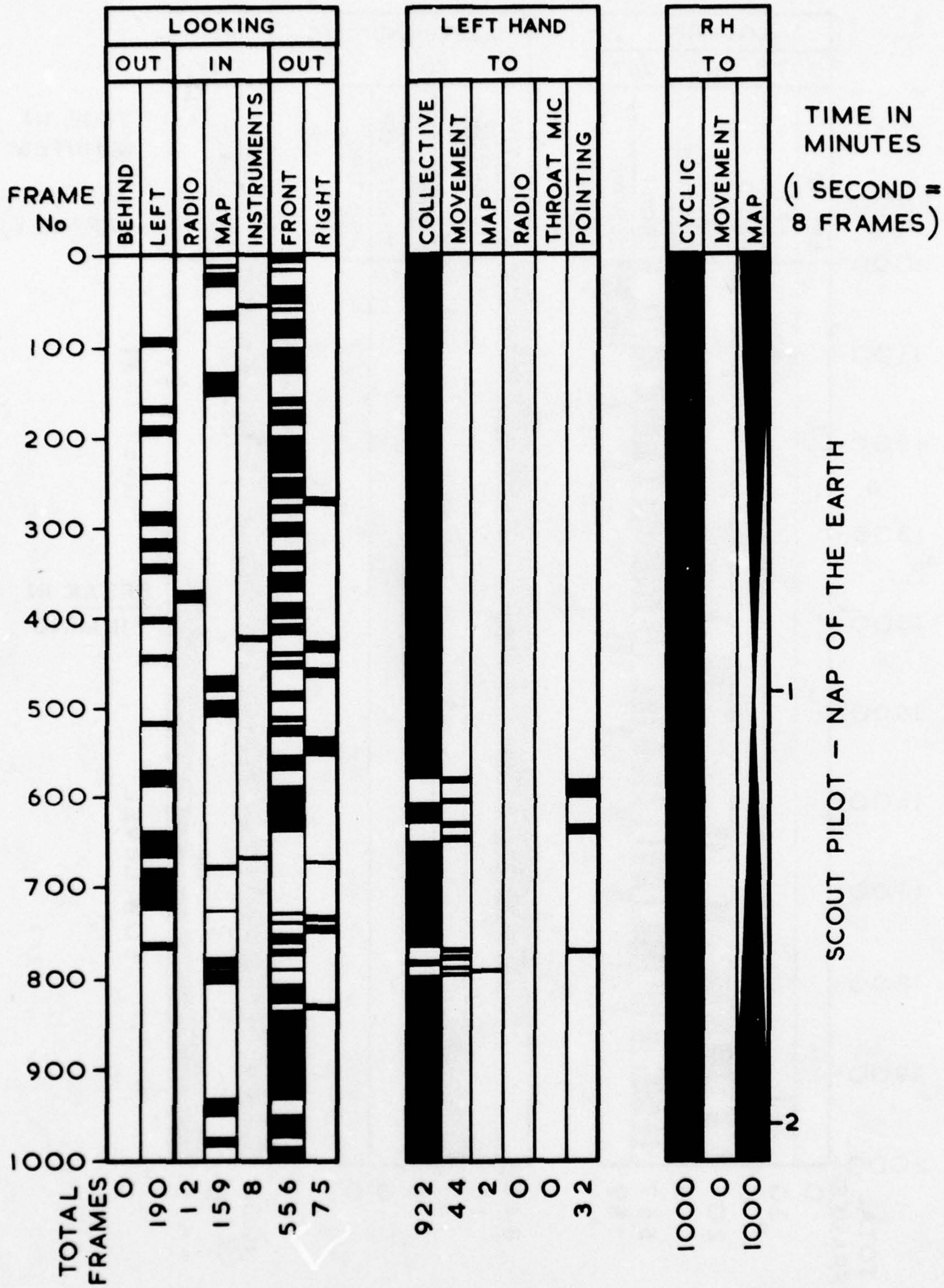

FIG. 4 HEAD AND HAND ACTIVITY OF SCOUT PILOT IN NORMAL FLYING CLOTHING DURING 'NAP OF THE EARTH' FLIGHT

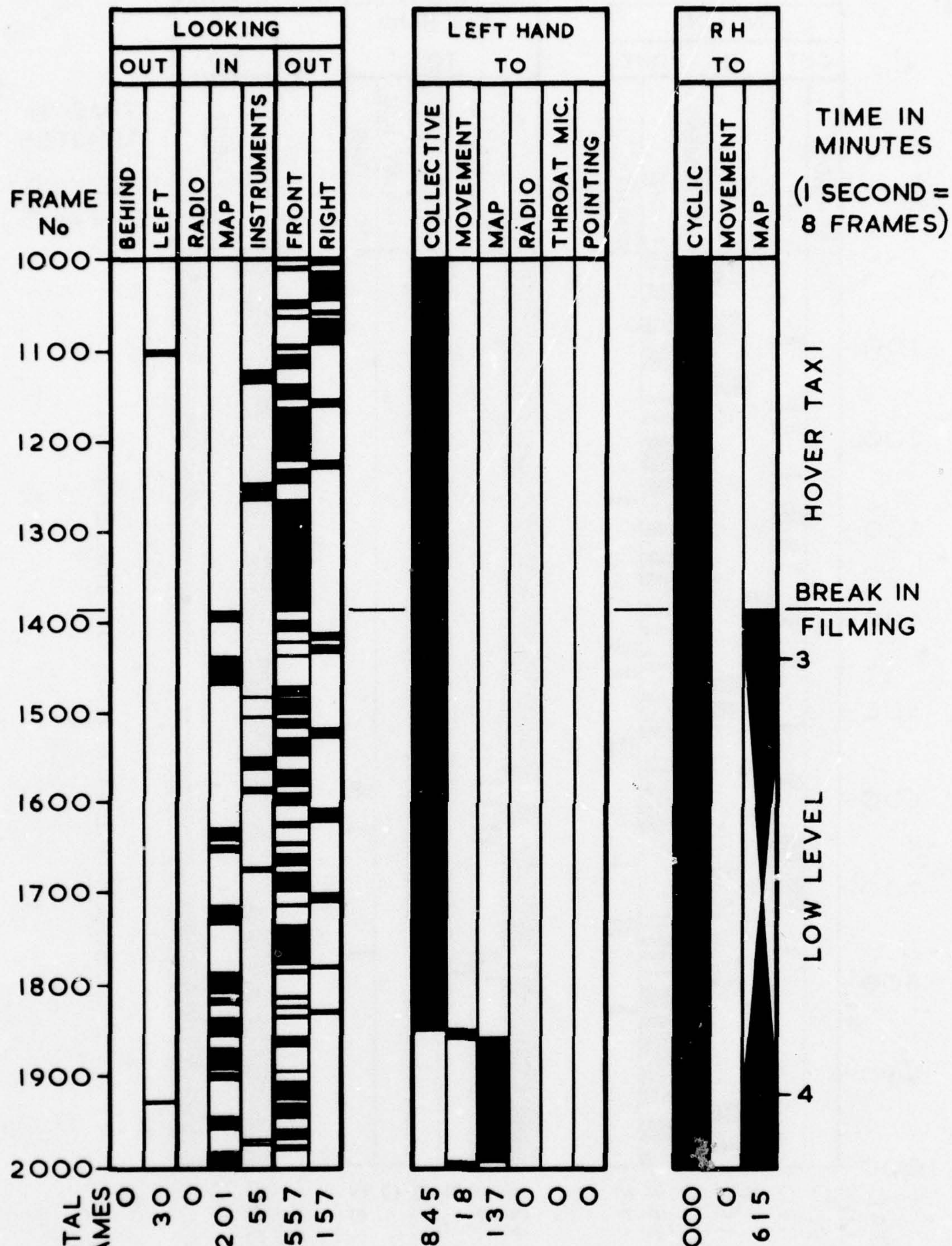

FIG. 5. HEAD AND HAND ACTIVITY OF SCOUT PILOT WEARING C.D. CLOTHING

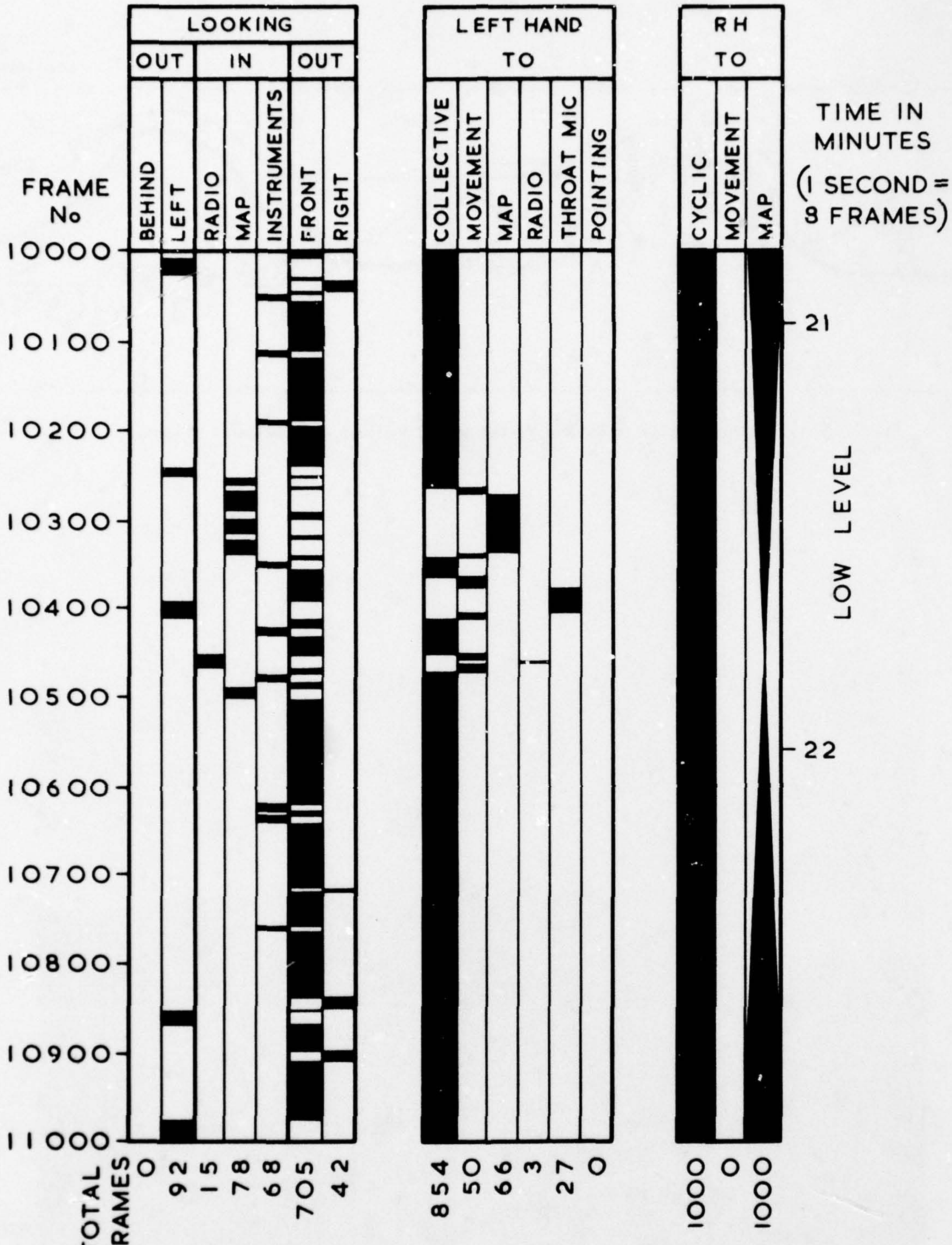

FIG.6. HEAD AND HAND ACTIVITY OF SCOUT PILOT DURING LOW LEVEL FLIGHT WITH C.D. HOOD REMOVED

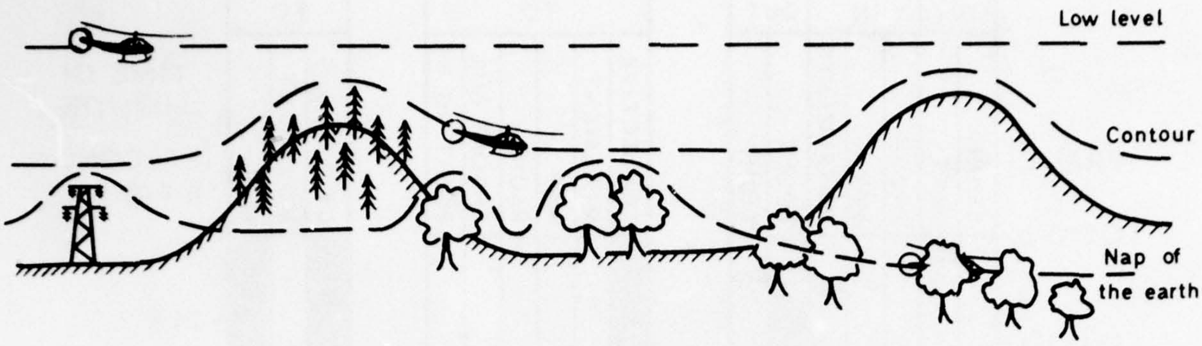

Fig 7 Pictorial representation of Nap of the Earth, Contour and low-level flight.

Fig 8 View from helicopter at 30 feet above the ground, showing the limited view ahead blocked by a wood.

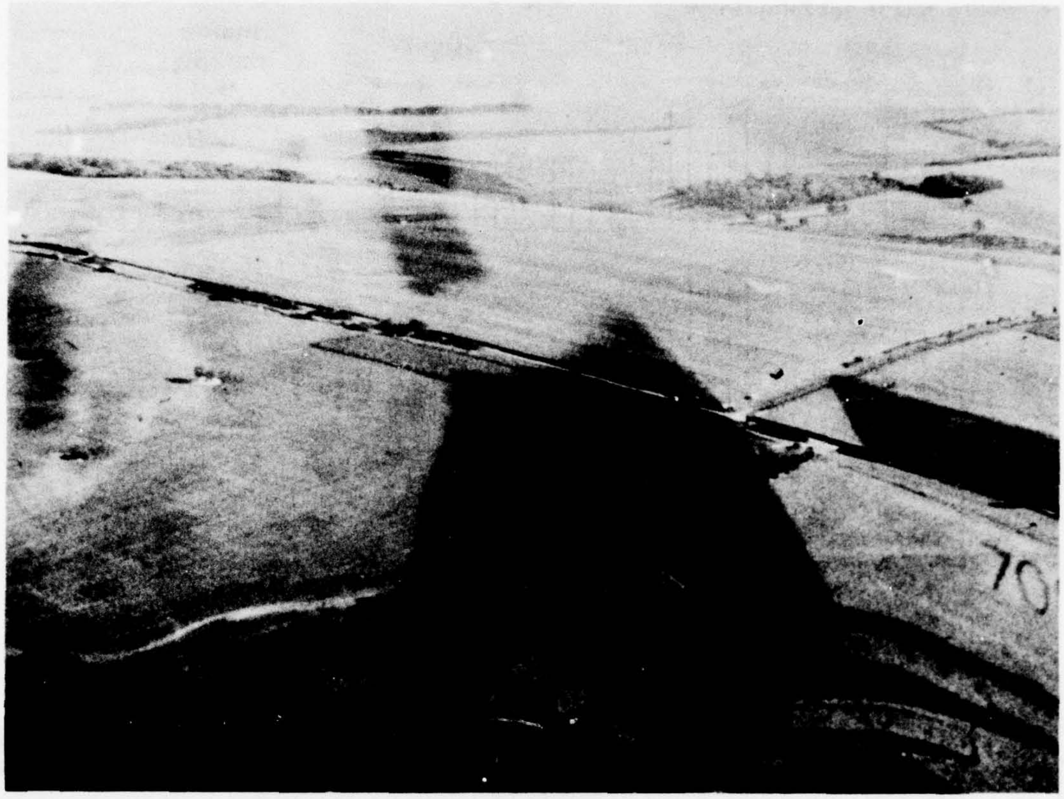

Fig 9 View from helicopter at 500 feet above the ground, showing excellent vision for navigation. The wood from the previous figure now appears at the bottom of the picture.

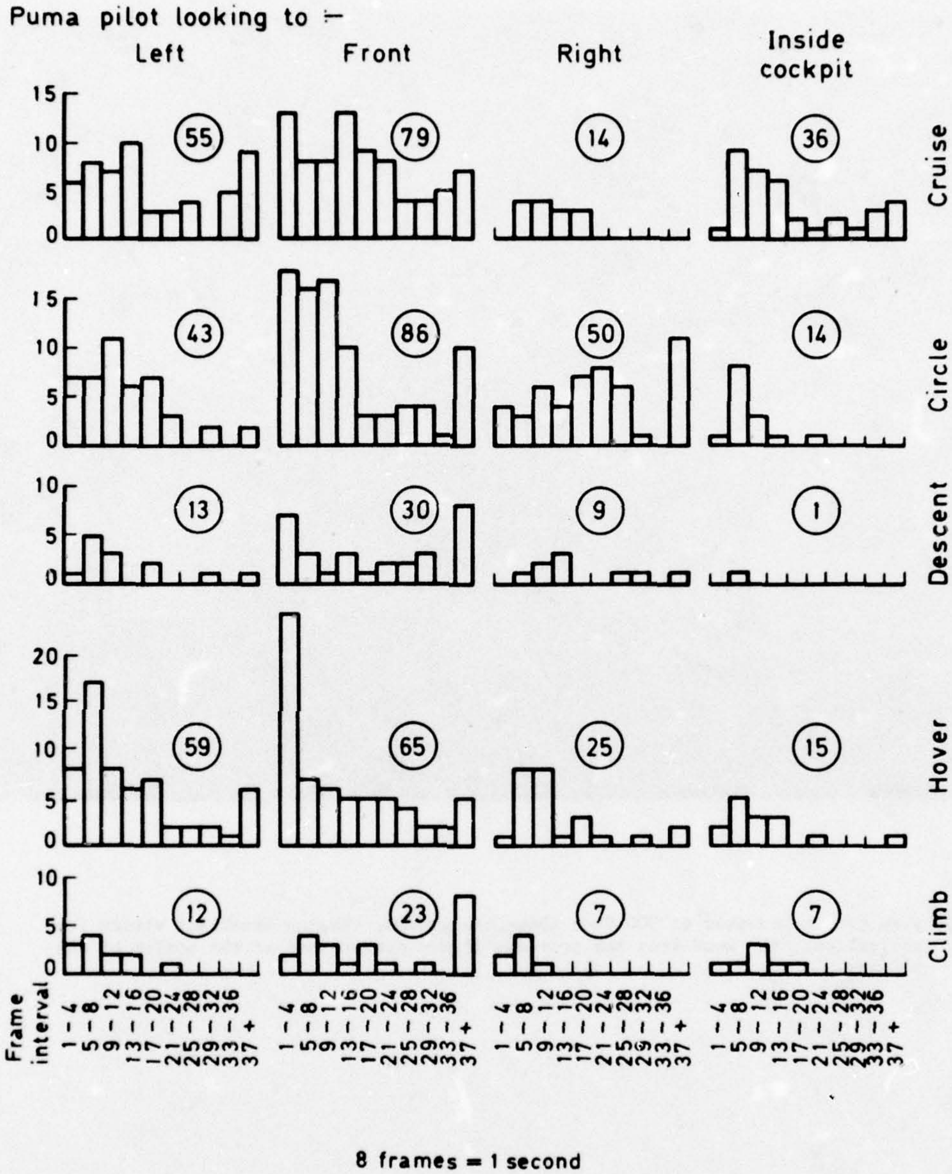

Fig 10 Frequency distributions of times (in frames) spent by a Puma pilot looking in particular directions during different phases of flight. Circled numbers indicate the total number of events per pilot viewing direction for each phase of flight.

DISCUSSION

K.A.Kimbal: Contrary to your opening remarks, I would submit that you have made an excellent first step in assessing a significant problem which we, at the Aeromedical Laboratory, are presently concerned with – that of the stress induced by required life support equipment for the chemical environment for helicopter pilots. I would appreciate very much continued information exchange with your organization on these matters.

R.R.Simmons: What is the average or normal airspeed which the Nap. of the Earth profile was flown?

E.J.Lovesey: 70-90 knots for Nap of the Earth, with perhaps up to 120 Kts at low level flights.

R.G.Ireland: In view of the maximum stress and strain imposed upon a pilot by the workload demands of a Nap of the Earth mission as we presently see it, are you able at this point to provide the mission planner with an upper time limit for pilot participation in such a mission, beyond which he must expect a rapidly deteriorating probability of mission success or mission completion.

E.J.Lovesey: We are unable to provide such a limit in the present state of our knowledge; however, it is imperative that investigation effort be applied to determine such answers as soon as possible.

THE ASSESSMENT OF ROTARY WING AVIATOR PRECISION PERFORMANCE DURING EXTENDED HELICOPTER FLIGHTS

by

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SUMMARY

To insure the most effective utilization of his aviation resources, the rotary wing flight commander requires information which describes how extended flight time affects the operational capability of his flight crews. In response to this requirement, the US Army Aeromedical Research Laboratory has conducted an investigation of the man-helicopter system performance during five days of extended flight. The current report describes the changes in pilot performance and aircraft stability on one of the maneuvers performed during the large scale fatigue investigation, the stabilized three-foot (.91 meter) precision hover. In addition, this report describes changes in subjective ratings of fatigue and flight performance, and changes in the measurement of auditory reaction time.

The results obtained during the current examination strongly suggest the occurrence of a learning effect across the first day of extended flight. The most stable hover performance was observed during the second flight day. By the third flight day, pilots attempted to maintain high quality precision hovers through an increase in the number of control inputs. Results obtained on the fourth day of flight suggest that the pilots have shifted their control technique from active control of the helicopter to a more passive strategy of responding to observed error.

Results from the subjective rating scales clearly demonstrate a progressive increase in the rated levels of fatigue between and within flight days. This increase in the level of fatigue corresponds to a general decrease in the ratings of flight performance.

INTRODUCTION

Today in the United States Army's helicopter fleet, there is major emphasis on developing the capability to perform tactical operations over an extended period of time. One area of concern within the development of this tactical staying power, is the lack of specific information, which describes the effects of fatigue and extended flight, upon the ability of the aviator to complete his assigned mission. The local flight commander requires an accurate and timely assessment of fatigue effects, and the establishment of basic flight time limitations, to insure effective management of his aviation resources. However, an arbitrary policy regulating flight time, would not preclude the possibility that a pilot could be unsafe with a fewer number of flight hours, nor would it provide the commander with the flexibility, or the effective management information that he needs. Thus, what the flight commander requires from aviation research is information which describes how extended flight time, and duty time, affect the actual operational capability of his flight crews. Presently the local commander has virtually no solid information that specifies the effects of fatigue on the rotary wing aviator's performance.

Previous investigations have examined the effects of fatigue on human performance,[1] but very little of the derived information is directly applicable in effectively determining operational limitations. Although extensive research has been accomplished in examining the effects of fatigue on fixed wing aviator performance, much of this research is not directly relevant to fatigue in rotary wing aviation, because of the substantial difference in flight envelopes, and aircrew tasking requirements.[2,3]

The experimental results presented in this report were obtained from a portion of the data acquired during a large scale field investigation of the effects of fatigue and extended flight on rotary wing flight performance. The preliminary results of this major investigation were presented to the AGARD panel meeting in Ankara, Turkey in 1975.[4] The current report describes changes in aviators' precision hovering skills during the extended flight operations. This examination focused on changes in aircraft stability and pilot control performance during extended flight.

METHODS AND PROCEDURES

Subjects for this investigation were six rotary wing aviators in excellent health, between the ages of 21 and 26. All pilots had recently completed the United States Army's Rotary Wing Flight Training. Each pilot had approximately 200 flight hours prior to his participation in the investigation.

The entire investigation was conducted at the US Army Aeromedical Research Laboratory's field facility, located in southeastern Alabama.

The in-flight portion of this investigation utilized three Army helicopters. One of these was the Aeromedical Research Laboratory's JUH-1H research helicopter, which was specially modified to provide information to the Helicopter In-Flight Monitoring System. The remaining two aircraft were standard Army UH-1H helicopters. One was used as a primary test vehicle, with the other used as a reserve test vehicle, and for maintenance of airborne systems.

In-flight performance data was obtained through the use of the Helicopter In-flight Monitoring System (HIMS). This research tool provides for the real time acquisition of all major aircraft motion, and pilot control parameters. HIMS monitors and records aircraft movements in all six degrees of freedom as well as all pilot control movements on the cyclic, collective, pedals, and the throttle. Measures of rates and accelerations along each axis are also obtained.

An on-board radio ranging system is utilized to constantly track the research aircraft's position. The HIMS continuously records 20 channels of information using an on-board incremental tape recorder.

Procedures for the Fatigue Investigation. Three general types of data were obtained during the investigation: (1) laboratory measures, (2) in-flight measures, and (3) subjective measures of performance and fatigue.

Laboratory testing included the cardiovascular monitoring of subjects, routine sampling of both blood and urine, measurement of dynamic visual acuity, and assessment of auditory reaction time. Objective measures of the man-helicopter in-flight system performance were obtained from the Helicopter In-Flight Monitoring System.

Throughout the flight testing portion of the fatigue investigation, subjective ratings were obtained, which assessed the pilot's fatigue intensity, his mood, and his overall flight performance for each flight period. Safety pilots, used throughout the flight testing, also evaluated the pilot's individual maneuver performance, and his overall flight performance for each flight period.

Field testing for the investigation was accomplished during three, ten-day periods with two pilots being tested during each period. Subjects were transported to the test facility 48 hours before the initiation of flight testing. This time period was used to obtain baseline data on the physiological and biochemical measures, and to permit the subjects to become familiar with the laboratory tasks.

Starting on the third day, a full schedule of in-flight performance measurement; physiological, biochemical, and perceptual motor measurement, and subjective rating was conducted. This testing schedule was maintained for approximately four and one-half days. The eighth, ninth, and tenth days of the test period were devoted to subject recovery and acquiring post-performance data.

The schedule of events for the five days of flight testing is presented in Table 1. The subjects were awakened at 0430 hours. Testing continued until 0100 hours the following day. Thirteen 50-minute flight periods were scheduled each day. During the in-flight testing, pilots received about three and one-half hours of sleep each night.

TABLE 1

SCHEDULE OF SLEEPING, EATING, FLYING AND TESTING

TIME FRAME	SUBJECT ACTIVITIES	EXPERIMENTAL MEASURES								
		Flight HIMS	Urine	Blood	IP Rating	Pupilometer	DVA	Reaction Time	Mood Scale	Fatigue Rating
0100 to 0430	Sleep Period		x							
0500 to 0600	Flight	x x x x	x	x	x					
0615 to 0800	Breakfast & Testing					x	x x	x	x	x
0800 to 0945	Flight	x x x x	x		x					x x
1000 to 1145	Flight	x x x x	x	x	x					x x
1200 to 1400	Lunch & Testing					x	x x	x	x	x
1400 to 1545	Flight	x x x x	x		x					x x
1600 to 1745	Flight	x x x x	x	x	x					x x
1800 to 2000	Supper & Testing					x	x x	x	x	x
2000 to 2145	Flight	x x x x	x		x					x x
2200 to 2345	Flight	x x x x	x	x	x					x x
2400 to 0100	Snack & Testing					x	x	x	x	x

During the flight periods, each subject acted as the primary pilot for either the instrumented research helicopter, or the standard Army helicopter. Each pilot was allowed 50 minutes to perform the maneuvers listed in Table 2. At the end of fifty minutes, both subjects returned to the landing area, quickly filled out the subjective rating scales, and then rotated to the other helicopter. The initial assignment of either the research helicopter, or the standard Army helicopter was counterbalanced between subjects for each day. Following this procedure, each subject provided one hour of in-flight performance data, for every two flight hours. During all flights, the pilots were accompanied by a safety pilot.

TABLE 2

FLIGHT PROFILE

Bad Weather

1.	3 ft. Hover - 1 minute	(Measured)
2.	360° Pedal turn - left about mast	(Measured)
3.	360° Pedal turn - right about mast	(Measured)
4.	Slope - right skid	(Measured)
5.	Slope - left skid	(Measured)
6.	Hover taxi	(Measured)
7.	Lateral hover	
8.	360° Pedal turn - left about nose	
9.	360° Pedal turn - right about nose	
10.	360° Pedal turn - left about pilot	
11.	360° Pedal turn - right about pilot	
12.	360° Pedal turn - left about tail	
13.	360° Pedal turn - right about tail	
14.	Rearward hover	(Measured)

Marginal Weather

15.	10 ft. Hover - 1 minute	(Measured)
16.	25 ft. Hover - 1 minute	(Measured)
17.	50 ft. Hover - 1 minute	(Measured)
18.	Simulated max-gross take off	(Measured)
19.	Traffic pattern 300 ft. AGL	(Measured)
	Crosswind	(Measured)
	Downwind	(Measured)
	Base	(Measured)
	Final	(Measured)
20.	Shallow approach	(Measured)

Good Weather

21.	Normal traffic pattern	(Measured)
	Crosswind	(Measured)
	Downwind	(Measured)
	Base	(Measured)
	Final	(Measured)
22.	Normal approach	(Measured)
23.	Max performance take off	(Measured)
24.	Low level flight	(Measured)
	Heading	(Measured)
	Altitude	(Measured)
	Airspeed	(Measured)
25.	Confined area landing	(Measured)
26.	Max performance take off	(Measured)
	Heading	(Measured)
	Altitude maintenance	(Measured)
	Airspeed	(Measured)
27.	Shallow approach	(Measured)

IFR (Hood)

28.	Standard rate climbing turn left to 180°	
29.	Maintain straight and level flight 15 sec.	
30.	Standard rate descending turn right to 180°	
31.	Deceleration to 40 knots	
32.	Acceleration to 90 knots	

The maneuvers listed in Table 2 were selected to provide realistic flight missions that could be performed over a wide range of weather conditions. Those maneuvers which were measured to assess fatigue effects on in-flight performance, are identified.

Measures Selected for the Current Examination. For the current report, only a portion of the information obtained during the major fatigue investigation was examined. This report describes the results obtained from analysis of the man-helicopter system performance on the stabilized three foot (.91 meter) precision hover maneuver. The three-foot precision hover was the first measured flight maneuver during each of the 50-minute flight profiles. In addition, the results on four of the subjective rating scales, and the subject's performance on the auditory reaction time task were also examined during the current investigation.

In-Flight Measures. Measures of man-helicopter in-flight system performance have been separated into two general categories: (1) those representing pilot control input, and (2) those which measure change in the helicopter's primary movement axes.

The information used to develop both the pilot control input, and aircraft status measures was obtained through the use of the HIMS. At each 50 millisecond sample period, throughout the data acquisition process, the location of each aircraft control was measured. The cyclic stick, which controls the tilt of the rotor plane, was measured in two axes - fore-aft and left-right. Position information was also obtained for the collective control, which determines the pitch of the main rotor system, and for the antitorque or pedal controls. These data provided the basic information for the derivation of values representing average control position, and the frequency, magnitude, and rate of control movement inputs. These measures were then used to determine changes in the pilot's control performance.

Two primary parameters of the pilot's control responses were: (1) the number of significant control movements he produces, and (2) the number of occurrences of control steady state, that condition where no

significant control movements are being produced. These parameters were developed using the limits specified in Table 3. Other major parameters were, the number of control reversals, and the percentage of time the pilot spends in control movement.

TABLE 3

CONTROL LIMITS FOR DETERMINING CONTROL MOVEMENT AND CONTROL STEADY STATE CONDITIONS

	Cyclic Fore/Aft	Cyclic Left/Right	Collective	Pedals
1. Time duration required for control steady state (in seconds)	.25	.25	.25	.25
2. Control movement limits (minimum rate value in inches)	.075	.075	.075	.075

For this particular investigation, several additional parameters of the pilot's control responses were developed. Using the procedure as outlined by Harper and Sardanowsky,[5] position data for each control channel was entered into a fast fourier transform. This procedure developed an index of the characteristic frequency (in hertz) of the pilots' control inputs. Two measures were selected from this transformation for further use. They were (1) the mode frequency, or that frequency where the maximum power was measured, and (2) the cut-off frequency, or that frequency where 95% of the power was applied at a lower frequency, and 5% was applied at a higher frequency.

The 28 variables, presented in Table 4, were determined to be the most relevant in determining the effects of fatigue on pilot control performance. These variables represent seven major parameters on each of the aviator's primary control channels.

TABLE 4

PILOT CONTROL INPUT VARIABLES

1. Cyclic Fore/Aft Control Absolute Control Movement Magnitude - Mean
2. Cyclic Fore/Aft Control Absolute Control Movement Magnitude - Standard Deviation
3. Cyclic Fore/Aft Control Mode Frequency
4. Cyclic Fore/Aft Control Cutoff Frequency
5. Cyclic Fore/Aft Control Percent of Time in Control Movement
6. Cyclic Fore/Aft Control Number of Control Movements Per Second
7. Cyclic Fore/Aft Control Number of Control Reversals Per Second
8. Cyclic Left/Right Control Absolute Control Movement Magnitude - Mean
9. Cyclic Left/Right Control Absolute Control Movement Magnitude - Standard Deviation
10. Cyclic Left/Right Control Mode Frequency
11. Cyclic Left/Right Control Cutoff Frequency
12. Cyclic Left/Right Control Percent of Time in Control Movement
13. Cyclic Left/Right Control Number of Control Movements Per Second
14. Cyclic Left/Right Control Number of Control Reversals Per Second
15. Collective Control Absolute Control Movement Magnitude - Mean
16. Collective Control Absolute Control Movement Magnitude - Standard Deviation
17. Collective Control Mode Frequency
18. Collective Control Cutoff Frequency
19. Collective Control Percent of Time in Control Movement
20. Collective Control Number of Control Movements Per Second
21. Collective Control Number of Control Reversals Per Second
22. Pedal Control Absolute Control Movement Magnitude - Mean
23. Pedal Control Absolute Control Movement Magnitude - Standard Deviation
24. Pedal Control Mode Frequency
25. Pedal Control Cutoff Frequency
26. Pedal Control Percent of Time in Control Movement
27. Pedal Control Number of Control Movements Per Second
28. Pedal Control Number of Control Reversals Per Second

Parameters utilized in this investigation to describe changes in the aircraft's stability were derived from measured changes in the pitch, roll and yaw axis. These data provided the basis for developing appropriate measures of aircraft stability and error during the maintenance of a controlled hover platform. Deviations from experimentally defined constants, and the rate of change in each axis were also measured.

The variables presented in Table 5, were selected as most relevant for describing changes in aircraft hover stability.

TABLE 5

AIRCRAFT ATTITUDE STATUS VARIBLES
SELECTED TO MEASURE AIRCRAFT STABILITY

1. Pitch Standard Deviation
2. Roll Standard Deviation
3. Heading Standard Deviation
4. Heading Average Constant Error From Initial Heading
5. Roll Rate Mean
6. Roll Rate Standard Deviation
7. Pitch Rate Mean
8. Pitch Rate Standard Deviation

Subjective Measures. Four subjective rating scales were examined during this investigation. Ratings of the subjects' overall flight performance, for each flight period, were obtained from both the subjects and the safety pilots, using a questionnaire modeled after the Cooper-Harper rating scale as discussed by Helms.[6] In addition, each subject rated his overall flight performance and fatigue intensity, by placing a mark on a line of standard length, a scoring technique effectively used by Hartman.[7]

Perceptual-Motor Measures. During in-flight testing, subjects received one hundred trials on an auditory reaction time task, three times daily. The means and standard deviation of the reaction time latencies were examined across flight days.

Analysis. The experimental design, for the present examination of the precision hover, divided the first four complete flight days into three time blocks per day. Each time block contained data from approximately four hours of flight which occurred either in the morning, afternoon, or evening of each flight day. In this manner, changes in performance across flight days, and within flight days, were addressed.

The primary analysis technique used throughout this investigation, was the multivariate analysis of variance. This technique provides for the simultaneous consideration of all dependent variables during significance testing. The multivariate analysis of variance also provides an indication of how many orthogonal, or unrelated, dimensions of performance are present in the dependent variables, and shows the relative contribution of each dependent variable, to each of these dimensions. This technique also provides an index of the relative position of each treatment group along significant dimensions of performance.

The 28 pilot control variables and the eight aircraft stability variables were examined using a three factor multivariate analysis of variance. The three factors were: (1) fatigue effects across flight days, (2) fatigue effects within the flight days, and (3) the effect due to intersubject variability. To accommodate for the repeated measures structure of the in-flight data, the intersubject variability was pooled with the normal error term for testing each of the main effects and their interaction. The five covariates found in Table 6, were also included in the multivariate analysis of pilot control and aircraft stability variables, to adjust for error contributed by the environmental and field investigation effects.

TABLE 6

COVARIATES USED TO ADJUST
FOR ENVIRONMENTAL AND FIELD EXPERIMENTAL EFFECTS

1. Daily Maneuver Sequence Number
2. Wind Speed (Knots)
3. Gust Speed (Knots)
4. Minutes of Fuel Burned Before The Start Of The Maneuver
5. Crosswind (Absolute Difference Between Average Heading and Wind Direction)

The variables examined in determining significant changes in the subjective ratings and the auditory reaction time task were also analyzed using a similar three factor multivariate analysis.

RESULTS AND DISCUSSION

The results of the analysis on pilot control variables are found in Table 7. It can be noted that there were significant differences across flight days and within the days of flight. Also, the interaction of days, and time of day, was not significant. This demonstrates that the effect of fatigue and extended flight, on pilot control, was consistent throughout the days of in-flight testing. The regressions (Table 7) of the covariates on each main effect, and their interactions, were also significant. These significant regressions demonstrated that knowledge of how many previous flights had been accomplished and knowledge of the prevailing wind conditions, was effective in predicting changes in pilot control variables. The error in obtained measures, that was accounted for by the five covariates, was then extracted. The remaining variability in pilot control variables could then be attributed to fatigue.

TABLE 7

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY
PILOT CONTROL MEASURES

	F Ratio	Mean Squares Tested	Degrees of Freedom for Hypothesis	Degrees of Freedom for Error	P Less Than	Root[a]
1. Day effect adjusted for five covariates	1.380	D/DS + WC	184.00	117.551	.053	1
2. Time of day effect adjusted for five covariates	1.587	T/TS + WC	56.00	68.00	.035	1
3. Day & time of day interaction adjusted for five covariates	1.160	DT/DTS + WC	168.00	325.963	.130	1
4. Regression of covariates on pooled day X subject interaction & within cells error (DS + WC)	1.841 1.430	Regression/ Residual Error	140.00 108.00	197.593 159.48	.001 .020	1 2
5. Regression of covariates on pooled time of day X subject interaction & within cells error (TS + WC)	1.704 1.390	Regression/ Residual Error	140.00 108.00	172.909 139.622	.001 .034	1 2
6. Regression of covariates on pooled day X time of day X subject interaction & within cells error (DTS + WC)	1.735 1.416	Regression/ Residual Error	140.00 108.0	271.647 219.054	.001 .016	1 2

[a]Only roots with significant results are presented.

The variables that contributed most to the overall discrimination between flight days (Table 8) were identified on the basis of their standardized discriminant function coefficient. From these data, it was determined that this between flight days performance dimension represented a continuum describing the quantity of control inputs. Thus, high values on this discriminant dimension, were associated with a relatively high number of control movement inputs.

TABLE 8

PRIMARY VARIABLES MEASURING CHANGES
IN PILOT CONTROL ACROSS FLIGHT DAYS

Pilot Control Variable	Standard Discriminant Function Coefficients
1. Collective control percent of total time in control movement	-1.554
2. Collective control number of control movements per second	1.494
3. Pedal control number of control reversals per second	1.366
4. Cyclic left/right control percent of total time in control movement	1.172
5. Collective control cutoff frequency	1.044
6. Cyclic left/right control number of control reversals per second	- .959
7. Cyclic fore/aft control cutoff frequency	- .865
8. Cyclic left/right control absolute control movement magnitude - Mean	.863
9. Pedal control absolute control movement magnitude - Mean	- .795

The relative level of each days flights along the dimension of control movement inputs is shown in Figure 1. These discriminant score contrast values indicate that during the first flight day, pilots produced the largest quantity of control inputs. By the second flight day, pilots showed a substantial

decrease in control inputs. On the third day, pilots again demonstrated increased control movement, but on the fourth day of flight, pilots produced the lowest quantity of control movement inputs.

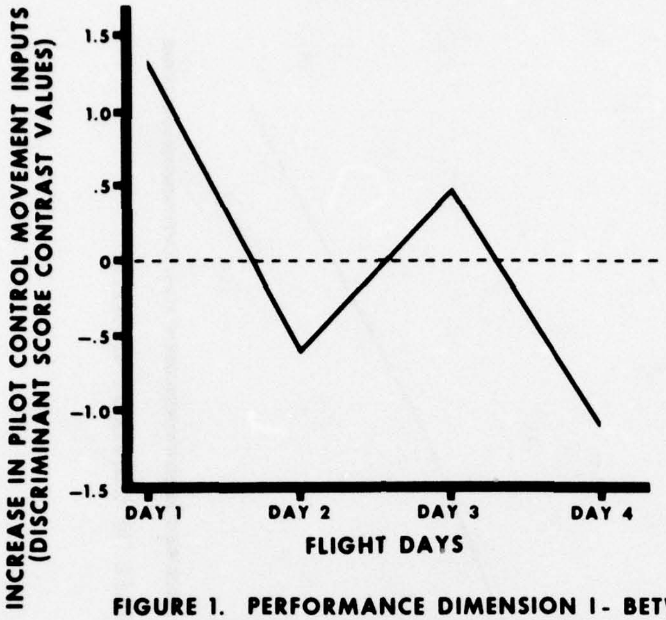

FIGURE 1. PERFORMANCE DIMENSION I - BETWEEN FLIGHT DAYS. OCCURRENCE OF PILOT CONTROL MOVEMENT INPUTS)

When the changes in pilot control inputs, between the daily flight periods were examined; the variables ented in Table 9 were identified as the major contributors to changes between the morning, afternoon and evening flights. The dimension of performance, within flight days, interpreted from these variables, was substantially different from that found between the days of flight. High values on the within days performance dimension, represented slow, irregular use of collective and pedal controls, increased lateral cyclic movement, and irregular fore-aft cyclic inputs. A high score on this dimension was interpreted as representing flights where there was a relatively high level of measured control input, but that the control input was not appropriate to maintaining a stable precision hover. Thus, the increase in control movement is associated with a corresponding decrease in control quality.

TABLE 9

PRIMARY VARIABLES MEASURING CHANGE IN PILOT CONTROL BETWEEN THE FLIGHT PERIODS WITHIN FLIGHT DAYS

Workload Variable	Standardized Discriminant Function Coefficient
1. Pedal control number of control movements per second	-2.362
2. Pedal control absolute control movement magnitude - Mean	-2.325
3. Cyclic left/right control absolute control movement magnitude - Mean	+2.218
4. Pedal control percentage of total time in control movement	+2.140
5. Collective control absolute control movement magnitude - Standard Deviation	+1.964
6. Pedal control mode frequency	-1.727
7. Cyclic left/right control absolute control movement magnitude - Standard Deviation	-1.591
8. Collective control absolute control movement magnitude - Mean	-1.290
9. Collective control percentage of time in control movement	-1.274
10. Cyclic fore/aft control absolute control movement magnitude - Standard Deviation	+1.026

The relative position of the morning, afternoon and evening flight periods, along the within day performance dimension, are presented in Figure 2. It can be noted from this illustration that there was a progressive increase in the quantity of control inputs from the morning to the evening flights. Since the control inputs did not contribute to improved maintenance of a stable hover, the increase in the quantity of control inputs shown in Figure 2, also represents a gradual decrease in the quality and effectiveness of those control inputs, throughout the flight day.

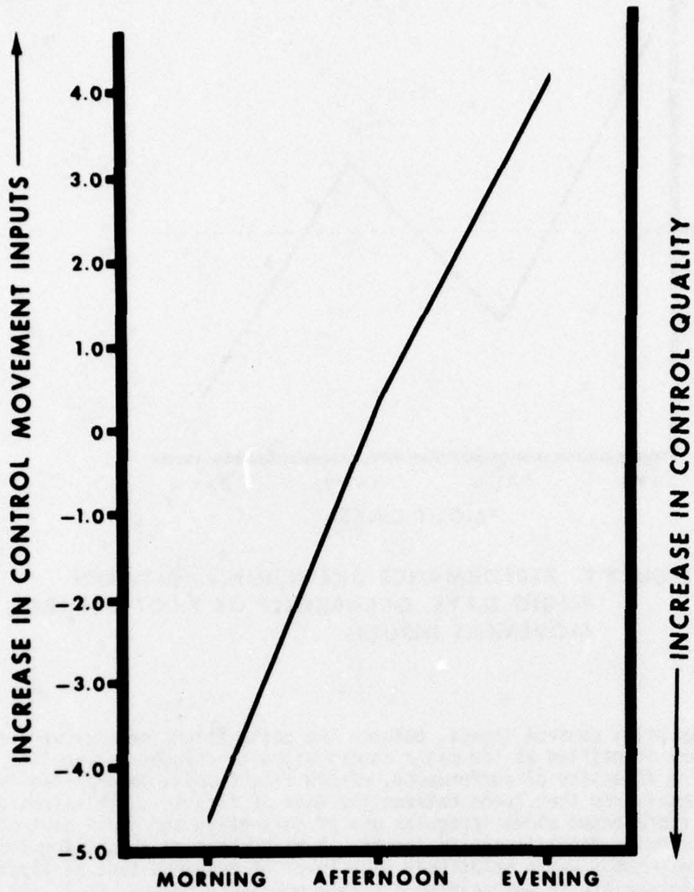

FIGURE 2. PERFORMANCE DIMENSION I - BETWEEN DAILY FLIGHT PERIODS. (LEVEL OF CONTROL QUALITY AND QUANTITY OF CONTROL MOVEMENT INPUT)

The analyses of the pilot control variables have identified several noteworthy changes in the level of pilot control input across the four days of flight. Examination of the daily level of control inputs (Figure 1) illustrates that there was a substantial decrease in the quantity of control inputs on the second flight day. This decrease in control input for the second flight day corresponded to high control quality and followed a learning trend over the first flight day. By the third flight day, the pilots demonstrated an increase in control inputs, as compared to day 2. The increase in control movement was apparently introduced in response to the increased fatigue brought on by 48 hours of extensive flight requirements. On the fourth flight day, the pilots dramatically decreased the amount of control movement input. However, further analysis has demonstrated that this decrease in control movement did not reflect improvement in hover maintenance, as observed in the second day; but rather, it demonstrated a substantial decrease in control quality brought on by the fatigue effects which accumulated over three days of extended flight.

The consistent increase in control quantity and decrease in control quality seen within the flight days (Figure 2), is particularly noteworthy, considering the substantial changes in the daily control input levels observed across the four flight days.

Aircraft Stability Measures. The results of the multivariate analysis of variance on the aircraft stability variables are presented in Table 10. Both the flight day, and within flight days, main effects, as well as their interaction were significant. Adjustment for environmental and experimental effects, through the use of covariates, was again effective as demonstrated by the significant regressions.

TABLE 10

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY
AIRCRAFT ATTITUDE STATUS MEASURES

	F Ratio	Mean Squares Tested	Degrees of Freedom for Hypothesis	Degrees of Freedom for Error	P Less Than	Root[a]
1. Day effect adjusted for five covariates	2.676	D/DS + WC	24.00	165.919	.001	1
	1.866		14.00	115.000	.037	2
2. Time of day effect adjusted for five covariates	3.555	T/TS + WC	16.00	104.00	.001	1
	4.040		7.00	52.50	.001	2
3. Test of day X time of day interaction adjusted for five covariates	1.744	DT/DTS + WC	48.00	358.333	.003	1
	1.293		35.00	319.135	.131	2
4. Regression of five covariates on pooled day X subject interaction & within cells error (DS + WC)	2.519	Regression/	40.00	251.252	.001	1
	1.739	Residual Error	28.00	213.801	.016	2
5. Regression of five covariates on pooled time of day X subject interaction & within cells error (TS + WC)	2.071	Regression/	40.00	229.457	.001	1
	1.484	Residual Error	28.00	195.362	.065	2
6 Regression of five covariates on pooled day X time of day X subject interaction & within cells error (DTS + WC)	2.480	Regression/	40.00	316.635	.001	1
	2.004	Residual Error	28.00	269.118	.003	2
	1.823		18.00	212.423	.024	3

[a]Only roots with significant results are presented.

The presence of a significant interaction between the day and time of day main effects, indicates that changes in aircraft stability were not consistent across the days of flight testing. Thus, this interaction was examined to determine what changes in aircraft stability did occur. Subsequent analysis identified two important dimensions of aircraft stability. Those variables which were major contributors to the observed differences between and within flight days, are presented in Table 11. The high discriminant scores on the first dimension of aircraft stability, were interpreted to represent erratic or relatively uncontrolled changes in the pitch and roll axis, or a relatively unstable hover platform. High discriminant scores on the second dimension of aircraft stability were interpreted to correspond to increases in the gross or observable error, measured for the pitch, roll and yaw axis.

TABLE 11

PRIMARY VARIABLES MEASURING CHANGE IN AIRCRAFT ATTITUDE
STATUS BETWEEN AND WITHIN FLIGHT DAYS

Aircraft Status Variable	Standardized Discriminant Function Coefficients
1. 1st discriminant function (Root I)	
a. Roll rate - Standard Deviation	-1.299
b. Roll axis - Standard Deviation	.965
c. Pitch rate - Standard Deviation	.673
2. 2nd discriminant function (Root II)	
a. Roll axis - Standard Deviation	1.068
b. Heading - Standard Deviation	.687
c. Pitch Rate - Mean	.445
d. Pitch rate - Standard Deviation	.441

The relative levels of stability for each flight day, and time period on both dimensions are presented in Figure 3. The discriminant scores contrast values indicated that the precision hover platform was most stable on the morning of the second flight day. However, by the evening of the second flight day a relatively high degree of erratic motion was observed. During the third day, the morning flights showed a slight improvement in aircraft stability from the previous evening. The afternoon flights on the third day showed a substantial increase in stability over the morning flights, followed by a slight decrease in stability for the evening period. This trend of stability shown on the third day, was not demonstrated on the fourth day of flight. For the fourth day, there was again an increase in aircraft stability for the afternoon period. By evening, the precision hover had become more unstable than the morning flights, in contrast to the third day where evening flights were more stable than morning flights.

The values on the second dimension of aircraft stability (gross or observable error), as presented in Figure 3, follow a trend similar to the hover instability dimension, except during the second flight day. During this day, an increase in hover instability, shown during the afternoon, is accompanied by a decrease in gross error. By the evening of the second day, the two aircraft stability dimensions again present similar patterns of change.

The analyses of the aircraft stability variables clearly demonstrate that there was an observable learning effect across the first flight day, resulting in the most stable hover on the morning of the second flight day. It is interesting to note (Figure 3) that the second flight day produced both the most stable and the least stable hover conditions. The results of the hover stability analyses have indicated that the rest period during the evening of the second flight day was only marginally effective in increasing the hover stability during morning flights on the third day. The afternoon period of the third flight day

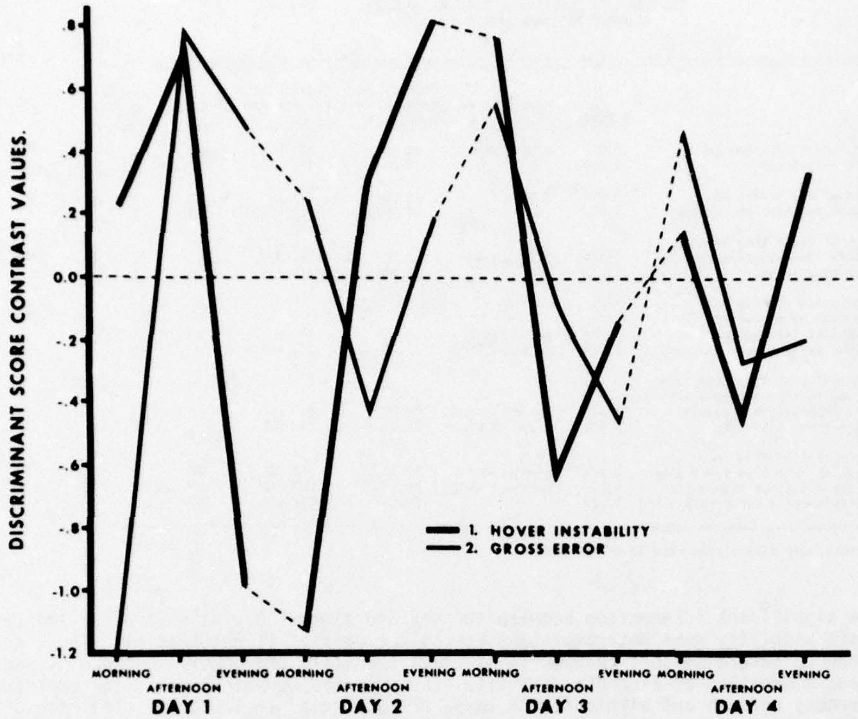

FIGURE 3. AIRCRAFT STABILITY DIMENSIONS 1. HOVER INSTABILITY 2. GROSS ERROR

produced a substantial increase in aircraft stability over the morning flights and demonstrated the highest level of observed stability for flights from the afternoon of the second day until the end of the fourth day.

The results of the pilot control and aircraft stability measures strongly suggest that there was a transition of the man-helicopter system performance after approximately 30-48 hours of extended flight requirements. During the second flight day, the aircraft's hover stability falls from the highest observed level in the morning to the lowest observed level in the evening. In a partially successful effort to re-establish high quality in the precision hover, the pilots increased the quantity of control inputs on the third day. By the fourth flight day, pilots appeared to abandon attempts to maintain hover quality through increased control movement. The sharp decrease in the level of control inputs observed on the fourth flight day was accompanied by relatively unstable hover performance and relatively high levels of observable error.

Subjective Measures and Laboratory Measures. In addition to the in-flight measures of pilot and aircraft performance, the current investigation also examined the subjective ratings of the pilot's fatigue and performance, and the perceptual-motor performance on the auditory reaction time task.

The results of the multivariate analysis of four subjective rating scales are found in Table 12. It is evident that there were significant differences between, and within flight days, on the subjective ratings of fatigue intensity and overall flight performance. These results (Table 12) also demonstrate that there was no significant interaction of the fatigue effects, or that the subject ratings were consistent between and within flight days.

TABLE 12

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY
SUBJECTIVE RATING MEASURES OF FATIGUE AND FLIGHT PERFORMANCE

	F Ratio	Mean Squares Tested	Degrees of Freedom for Hypothesis	Degrees of Freedom for Error	P Less Than	Root
1. Day Effect	23.195	D/DS + WC	12.00	603.523	.001	1
2. Time of Day Effect	11.034	T/TS + WC	8.00	446.000	.001	1
	5.194	T/TS + WC	3.00	223.500	.002	2
3. Day X Time of Day Interaction	.865	DT/DTS + WC	24.00	848.936	.651	1

For the subjective ratings, there was only one significant dimension of change across flight days. The standardized discriminant function coefficients for each rating scale (Table 13) demonstrate that the rated level of the subjects' fatigue was the major contributor to the differences observed between flight days. For subjective ratings between daily flight periods, there were two dimensions of difference (Table 13). On the first dimension, a high discriminant score represents a high rating of fatigue and a low rating of performance. On the second dimension of change between daily flight periods, a high discriminant score represented a situation where the pilot rated himself as being low in fatigue with a correspondingly high rating on one scale of overall performance. The safety pilot, on the other hand, provided a lower rating of the pilot's overall performance.

TABLE 13

VARIABLES MEASURING CHANGES IN SUBJECTIVE RATINGS ON FATIGUE AND FLIGHT PERFORMANCE

Variables	Standardized Discriminant Function Coefficients	
1. *Changes Between Days*	Root I	
a. Fatigue intensity - subject rated line scale	1.064	
b. Overall flight performance - subject rated line scale	.015	
c. Flight performance - safety pilot rated - Cooper-Harper scale	.055	
d. Flight performance - subject rated - Cooper-Harper scale	.267	
2. *Changes Between Flight Periods*	Root I	Root II
a. Fatigue intensity - subject rated line scale	.534	-.644
b. Overall flight performance - subject rated line scale	-.041	.462
c. Flight performance - safety pilot rated - Cooper-Harper scale	.183	-.824
d. Flight performance - subject rated - Cooper-Harper scale	-.728	-.580

The discriminant score contrasts presented in Figure 4 clearly illustrate a progressive increase in the subjects' fatigue intensity rating across flight days. The contrasts between the daily flight periods

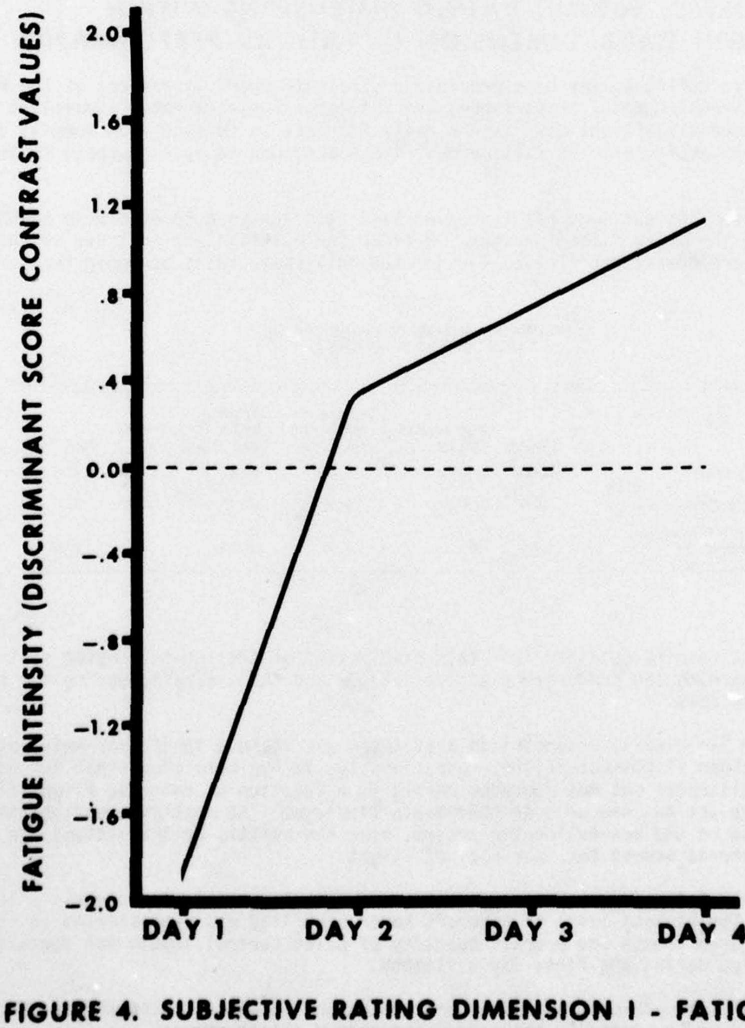

FIGURE 4. SUBJECTIVE RATING DIMENSION I - FATIGUE INTENSITY BETWEEN FLIGHT DAYS

on the first dimension (Figure 5), demonstrate that the rating of fatigue increases throughout the day, as the rating of performance decreases.

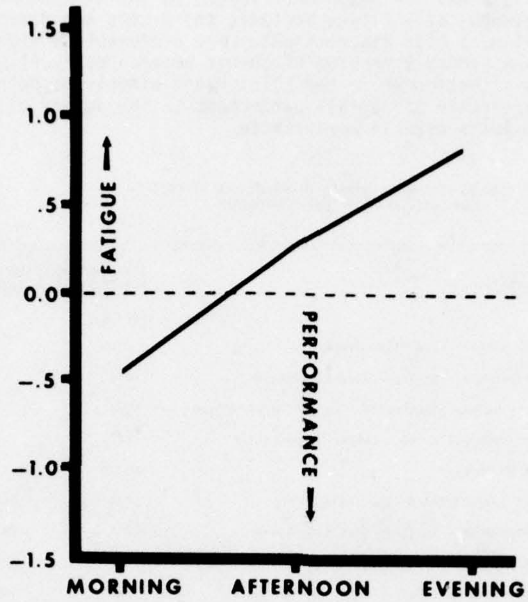

FIGURE 5. SUBJECT RATING DIMENSIONS WITHIN FLIGHT DAYS. DIMENSION I - FATIGUE/PERFORMANCE

Thus, the subjective rating scales have provided a straightforward assessment of the relationship between extended flight requirements, performance, and fatigue. Subjects rated themselves as increasing in fatigue with each successive flight day, with a daily increase in fatigue from morning to evening. Over the four flight days an increase in fatigue rating was accompanied by a decrease in the performance quality rating.

Results obtained from the auditory reaction time task were analyzed to determine changes across flight days and between the daily flight periods. Neither the multivariate analysis of the response latency means and standard deviations (Table 14), nor the univariate tests of these two variables were significant.

TABLE 14

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY
TESTS OF CHANGES IN REACTION TIME

	F Ratio	Mean Squares Tested	Degrees of Freedom For Hypothesis	Degrees of Freedom For Error	P Less Than	Root
1. Day Effect	1.831	D/DS	6.00	16.00	.156	1
2. Time of Day Effect	.541	T/TS	6.00	16.00	.770	1
3. Day X Time of Day Interaction	1.023	DT/DTS	18.00	52.00	.451	1

CONCLUSIONS

On the basis of the results obtained from this examination of the man-helicopter system performance, several conclusions regarding the performance of the aviator and the aircraft, during the precision hover maneuver, have been developed.

This investigation has clearly demonstrated that there are changes in the man-helicopter system performance during extended flight conditions. Additionally, it has been shown that the complex skill required in flying a helicopter was not degraded merely as a function of extended flight time. However, it should be noted these are not new or even remarkable findings. The most interesting aspects related to the effect of fatigue on the man-helicopter system, were the shifts, or transitions, in the aviator's control performance observed across the four days of flight.

Examination of control input performance and aircraft stability strongly suggests a learning effect across the first day. The highest level of aircraft hover stability was demonstrated on the morning of the second flight day, even though the overall quantity of pilot control inputs had decreased from the level previously observed during the first day's flights.

Between the daily flight periods, a gradual and consistent increase in the number of control inputs was observed. However, even as early as the end of the second flight day, it was evident that this general increase in control inputs was progressively less effective in maintaining a stable hover condition.

The aircraft stability observed on the morning of the third day was degraded from that seen during the previous evening. The overall number of control inputs for the third day increased substantially from the level observed during the second day. This increase in control inputs, while effective in providing a stable hover for the afternoon flights, became considerably less effective by the evening of the third day.

In the morning flight period of the fourth day, there was a marked decrease in hover stability as compared to the previous evening. During the afternoon, the hover stability again improved from the morning flights, but by evening, precision hover stability had fallen far below that seen on the previous evening. Thus, this assessment of the precision hover maneuver appears to have identified a situation where the pilot shifted his control performance strategy from active control of the helicopter, through the introduction of a high level of control inputs for the third day, to a more passive strategy of merely responding to gross changes in the aircraft's attitude and position on the fourth day.

In summary, the analysis and subsequent interpretation of these data from four days of extended flight, strongly suggest a measurable learning effect over the first 24 hours, represented by a high degree of hover stability and a relatively low occurrence of control movement input on the morning of the second flight day. In response to fatigue introduced by 48 hours of extended flight, pilots attempted to maintain hover stability by increasing the quantity of control movement inputs. After 72 hours of extended flight, pilots shifted their strategy from aggressive control of the helicopter to a more passive strategy of responding to observed error in attitude and position.

In conclusion, it must be pointed out that the precision hover is only one of several types of maneuvers measured during the major fatigue investigation. As analyses and subsequent interpretation of the other flight maneuvers are accomplished, it is expected that a more complete understanding of the effects of extended flight, and fatigue, on the man-helicopter system, will be developed.

DISCLAIMER

The findings in this report are not to be considered as an official Department of the Army position unless so designated by other authorized documents.

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EVALUATION DE LA CHARGE DE TRAVAIL DES PILOTES D'HELICOPTERES ENREGISTREMENTS EN VOL DE LA FREQUENCE ET DE LA VARIABILITE DU RYTHME CARDIAQUE.

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RESUME

Les enregistrements en vol de la fréquence cardiaque et de la variabilité du rythme cardiaque sont effectués chez 4 pilotes d'essai d'hélicoptère du C.E.V. au cours d'approches I.L.S. de difficultés croissantes : vol sans visibilité de jour et de nuit. Vitesse (VI) d'approche décroissante.

Cinq types de tâche sont définis, chaque type étant répété 5 fois au cours du même vol. Les impressions ressenties et les difficultés rencontrées sont également notées de 1 à 10.

Les résultats obtenus font ressortir une augmentation de la fréquence cardiaque avec baisse concomittente de la variabilité cardiaque d'autant plus importante que le sujet a une grande variabilité au repos. Cette augmentation du rythme cardiaque est exacerbée par l'adjonction de facteurs externes (turbulence). L'influence de l'apprentissage est marquée par une diminution sensible de cette accélération cardiaque au cours de répétitions successives d'une même tâche. L'adjonction de critères subjectifs peut parfois apporter quelques renseignements utiles.

L'étude de la variabilité cardiaque parait être un critère supérieur à l'enregistrement de la fréquence cardiaque instantanée, cependant on ne peut pas encore affirmer une proportionnalité étroite entre ces paramètres et la charge de travail aérien.

INTRODUCTION

Le travail aérien représenté par le pilotage est essentiellement une tâche intellectuelle où les efforts musculaires proprement dits sont le plus souvent relativement réduits. Le travail du pilote peut se résumer en trois actions principales :

- l'acquisition de données indispensables au pilotage et au déroulement de la mission,
- l'analyse de la situation,
- la réponse effectuée.

Cette tâche se trouve singulièrement compliquée lorsqu'il s'agit pour le pilote de réaliser des approches I.L.S. dans des conditions environnantes extrêmement difficiles.

La mesure directe quantitative de la charge de travail imposée dans de telles circonstances est pratiquement impossible. Cependant toute une série de méthodes ont été proposées, aussi bien sur le plan physiologique que psychologique.

Les physiologistes étudient et enregistrent : l'activité électrique cérébrale, l'état de tonus et de contraction musculaire, les mouvements oculaires, la résistance cutanée, la fréquence respiratoire, la fréquence cardiaque, etc...

Les psychologues recueillent après le vol les commentaires de l'équipage sur la nature et les notations sur la difficulté de la tâche à accomplir. Ces notations sont effectuées selon une échelle de difficulté.

L'analyse de ces différents paramètres psycho-physiologiques traduit plus ou moins l'état de réceptivité et de réactivité des sujets, donc leur niveau de vigilance.

Pour réaliser des enregistrements en vol il est indispensable de choisir une méthode simple apportant le minimum de gêne pour le pilote, n'interférant pas sur son travail et n'entraînant aucune incidence sur la sécurité.

C'est pour ces raisons que nous avons été amenés à utiliser une technique d'enregistrement de la fréquence cardiaque et de la variabilité cardiaque conjointement à une enquête psychologique : établissement après le vol d'une fiche de notation correspondant à l'échelle de Cooper (voir tableau ci-après).

QUALIFICATIF	Note	Description des conditions de charge de travail	Peut atterrir
Satisfaisant	1	Excellentes - parfait.	oui
	2	Bonnes - travail agréable.	oui
	3	Satisfaisantes malgré quelques difficultés	oui
non satisfaisant	4	Acceptables mais devenant désagréables	oui
	5	Difficulté limite pour une opération normale	oui
	6	Acceptables seulement dans des conditions d'urgence	oui
non acceptable	7	Inacceptables même en cas d'urgence	douteux
	8	Inacceptables - dangereuses	non
	9	Inacceptables - incontrôlables	non
impossible	10		

En effet, le rythme cardiaque suit les fluctuations d'une tâche perceptive : travail visuel. Si au repos la période cardiaque est instable et varie physiologiquement : arythmie sinusale, comme l'a montré KALSBEEK, cette irrégularité diminue d'une façon significative avec la charge mentale alors que dans le même temps la fréquence cardiaque croît. Cette augmentation pourrait être ainsi un très bon critère d'étude des charges visuelles perceptives.

Nous avons donc cherché à apprécier l'intérêt de l'étude du rythme cardiaque et de sa variabilité dans l'évaluation de la charge de travail imposée à différents pilotes, au cours d'approches I.L.S. sur hélicoptère.

Le pilotage des hélicoptères est particulièrement délicat, vu l'instabilité propre de ces aéronefs. Cette tâche est rendue encore plus difficile sur les hélicoptères lourds. Ceci oblige les constructeurs à concevoir des systèmes d'aide automatique au pilotage pour améliorer les qualités de vol de ces machines et en rendre le pilotage agréable.

Dans notre expérimentation, les approches sont effectuées sans aide automatique, ce qui explique la difficulté et la complexité de la tâche demandée.

Protocole d'essai

Ces mesures sont faites sur 4 pilotes d'essai du Centre d'Essais en Vol dont l'âge s'échelonne de 35 à 50 ans, sujets particulièrement bien entraînés et motivés pour ce type d'expérimentation.

La tâche requise consiste en l'atterrissage d'un hélicoptère Super Frelon sur faisceau ILS ou éventuellement sur faisceau à grande pente du type TALAR, tous les atterrissages sont réalisés sur la piste du C.E.V. à BRETIGNY.

Cinq types de tâche sont définis :

1 - Sans pilote automatique
de jour avec bonne visibilité extérieure
Vitesse d'approche constante : VI = 100 kts.

2 - Sans pilote automatique
sous capote
Vitesse d'approche constante : VI = 100 kts.

3 - Sans pilote automatique
sous capote
Vitesse d'approche décroissante : VI = 100 à 40 kts.

4 - Sans pilote automatique
de nuit sans écran - piste éteinte
Vitesse d'approche décroissante : VI = 100 à 40 kts.

5 - Avec pilote automatique
sous capote
Vitesse d'approche décroissante : VI = 100 à 40 kts.

Chaque pilote doit effectuer la tâche donnée cinq fois de façon répétitive afin de détecter un facteur éventuel d'apprentissage et d'adaptation à la tâche.

La mesure du rythme cardiaque est assurée à partir de 3 électrodes cutanées de grande surface, placées dans la région sous-mamelonnaire (2 électrodes) et paravertébrale (1 électrode) (Fig. 1), délivrant des tensions différentielles appliquées à l'entrée d'un amplificateur C.S.F. La sortie de l'amplificateur est enregistrée :

- directement sur une piste de la bande magnétique,

- indirectement sur une autre piste à travers le "normalisateur d'impulsion" qui élimine la perturbation du cardiogramme par les contractions musculaires et délivre une impulsion adaptée au programme de calcul (Fig. 2).

- Description d'une expérience

Le pilote une fois équipé des électrodes de l'électrocardiogramme s'asseoit à son poste et connecte ses électrodes à l'électronique associée par l'intermédiaire d'une prise rapide directement décrochable.

Après avoir décollé et réalisé un circuit autour du terrain, il effectue sa tâche d'atterrissage selon le plan suivant :

- à 1 500 pieds interception du localiseur : VI = 100 kts,mise en route de l'enregistrement magnétique, interception du glide ;

- top à 1 000 pieds,

- nouveau top à 600 pieds. Dans le cas d'essai à VI décroissante, il est demandé au pilote de faire décroitre cette vitesse à partir de 600 pieds de façon linéaire pour atteindre 50 à 40 kts à 50 pieds..

- descente jusqu'à 50 pieds,

- à 50 pieds, remise des gaz, nouveau circuit pour reprendre la même manoeuvre.

L'allumage de lampes signale un écart trop important et la non réussite de l'approche et la nécessité de la remise des gaz.

A la fin de chaque série (5) les pilotes de retour au sol remplissent deux feuilles sur lesquelles ils inscrivent leurs impressions générales sur les difficultés rencontrées qu'ils notent de 1 à 10 (planches 1 et 2).

Au cours du vol, l'expérimentateur de bord remplit une autre feuille consignant les caractéristiques du vol, ainsi que les observations du pilote.

- Dépouillement des enregistrements

Le battement cardiaque est transformé en un signal électrique du niveau et de durée normalisée. L'enregistrement est donc celui de créneaux synchrones avec les contractions cardiaques et d'une base de temps.

Si t_n est le temps d'apparition de la nième pulsation, on appelle :

- période cardiaque :

$$T_n = t_{(n)} - t_{(n-1)} \qquad \text{(secondes)}$$

- Fréquence cardiaque :

$$F_n = \frac{1}{T_n} \times 60 \qquad \text{(pulsations par minute)}$$

- Variabilité

$$V_n = T_{(n)} - T_{(n-1)}$$

- Résultats

Ils sont exprimés sur les tableaux 1, 2, 3, 4 et les figures 3, 4 et 5.

Chaque tableau représente la valeur moyenne pour chaque type de tâche répétée 5 fois, de la fréquence cardiaque (en battements/minute) et de la variabilité cardiaque (en ms) avec leur écart type.

Dans la première colonne, intitulée,numéro de vol, le nombre placé entre parenthèses indique le type de tâche. Pour des raisons techniques la tâche 5 ne figure que chez deux pilotes (tableau 1 et tableau 2).

Les chiffres représentés dans la troisième et la sixième colonne, indiquent le nombre d'échantillons choisis (nb)

La fréquence cardiaque, en moyenne de 65 à 70 battements par minute au repos passe à 75 - 80 et même plus pour 3 de nos sujets (tableaux 1 - 2 et 3), chez un seul (sujet LOR) elle est supérieure à 100 pour deux types d'approche (tableau 4 (2) et (3)), cette accélération importante est due, comme nous le verrons, à des causes perturbatrices extérieures. Dans l'ensemble on observe une baisse de cette accélération cardiaque au fur et à mesure de la répétition de la même tâche (en moyenne 4 à 5 battements par minute) et ce d'autant plus que la fréquence est élevée au cours de la première approche (tableau 2 (4) - tableau 3 (2)).

La variabilité cardiaque diminue au fur et à mesure de l'augmentation de la fréquence cardiaque (Fig. 3 et 4) alors qu'au repos, elle est extrêmement fluctuante et dépend de l'arythmie sinusale du sujet, souvent liée au rythme respiratoire.

En ce qui concerne les notations données aux différentes tâches 1 - 2 - 3 - 4 - 5-elles sont extrêmement variables d'un sujet à l'autre.

D'une façon générale les notes les plus élevées 6, 7 sont données pour les tâches 3 - 4 : sous capote de jour avec VI décroissante - et de nuit piste éteinte VI décroissante, ce qui correspond souvent avec une accélération cardiaque.

- Discussion

A la suite d'une telle expérimentation, deux enseignements importants peuvent être tirés :

- une augmentation de la fréquence cardiaque,

- une légère diminution de cette augmentation au cours de répétition de la tâche donnée.

On observe une augmentation constante de la moyenne de la fréquence cardiaque au cours d'une tâche de pilotage donnée par rapport à la fréquence moyenne de repos. Cette augmentation est de l'ordre de 10 à 15 battements/minute et correspond à celle constatée par HASBROOK et coll. lors d'approches ILS sur simulateur.

A cette augmentation correspond une baisse de la variabilité cardiaque, baisse d'autant plus importante que le sujet présente une variabilité importante au repos.

Dans la figure 4 on voit qu'elle finit par disparaître en fin d'approche lors du travail aérien maximum, alors que la fréquence cardiaque instantanée est très importante supérieure à 110 battements/minute. Le pilote estime d'ailleurs cette tâche tres difficile et la cote 7, c'est-à-dire : inacceptable, même en cas d'urgence. Dans la réalité un tel atterrissage resterait douteux et obligerait le pilote à remettre les gaz.

On note dans l'ensemble une diminution plus ou moins importante de la moyenne de l'augmentation du rythme cardiaque au cours de la répétition de la même tâche. Cette diminution est de l'ordre de 5 à 10 battements en moyenne, entre la première approche et la cinquième, sauf cas exceptionnels où des facteurs externes viennent interférer sur l'accomplissement de la tâche, turbulence par exemple. Cette baisse à long terme pourrait être attribuée selon HASBROOK et coll. a un effet d'accommodation et au rôle de l'apprentissage.

L'augmentation de la fréquence cardiaque peut à notre avis être attribuée au "stress" représenté par le taux d'appréhension et l'attention soutenue du pilote au cours de son approche. Cette augmentation est d'ailleurs exacerbée lorsque des facteurs externes viennent interférer. C'est le cas du sujet LOR qui présente au cours des tâches 2 et 3 une augmentation de la moyenne de la fréquence cardiaque très importante supérieure à 100 battements 117 - 113 - 107 - 104. Or ce pilote a du réaliser son approche de type 2 dans un trafic aérien dense, la présence d'un Mirage dans le circuit l'obligeant à effectuer une "baïonnette" et une remise intempestive des gaz, il s'ensuit d'ailleurs une vive altercation entre ce pilote et le contrôleur au sol. Dans l'approche de type 3, le facteur externe est représenté par une mauvaise météo : présence de turbulences et rafales qui gênent considérablement le pilote et l'empêche d'effectuer une décroissance linéaire de sa vitesse d'approche.

Un autre facteur intéressant à analyser consiste en la comparaison entre les notations données par les pilotes les enregistrements physiologiques : fréquence, variabilité cardiaque et les résultats de la performance.

Peut-on dire qu'il existe une corrélation étroite entre eux ? A notre avis il ne nous paraît pas possible de répondre de façon absolue à une telle question. Ces notations subjectives dépendent des sujets : certains notent de façon optimiste 3 à 4 alors que l'approche est ratée, d'autres de façon pessimiste 5 - 6, parfois 7, alors que la mission est parfaitement exécutée, la fréquence cardiaque augmentant, la variabilité cardiaque diminuant plus ou moins.

Sur le tracé 5 on constate pour une approche de type 3, une variabilité cardiaque pratiquement inchangée, une légère suraugmentation de la fréquence cardiaque en fin d'approche, pourtant ce pilote note la difficulté 6 à savoir : à peine acceptable dans un cas d'urgence, pourtant il réussit parfaitement son approche. Il convient de signaler qu'il s'agit d'un sujet relativement âgé, pilote d'hélicoptère très confirmé, parfaitement entraîné mais toujours conscient de la tâche demandée.

Il nous semble donc qu'à l'heure actuelle, on ne puisse pas affirmer l'existence d'une proportionnalité étroite entre la charge de travail, la fréquence et la variabilité cardiaque.

CONCLUSION

Les enregistrements de la fréquence cardiaque et de la variabilité cardiaque sont effectués chez 4 pilotes d'essai d'hélicoptère du Centre d'Essais en Vol au cours d'approches ILS de difficultés croissantes. Comme il avait été déjà démontré par AUFFRET et Coll., l'enregistrement de ces paramètres, paraît être un critère utile pour l'évaluation de la charge de travail aérien ou la détection des variations de charge au cours de ce travail à prédominance perceptive. L'adjonction de critères subjectifs peut également apporter des renseignements utiles, mais ces critères devraient être simplifiés, la cotation de 1 à 10, selon l'échelle de Cooper, apparaissant à notre avis un peu trop complexe.

L'étude de la variabilité cardiaque paraît être un critère supérieur à l'enregistrement simple de la fréquence cardiaque instantanée.

Une telle méthode d'enregistrement de réalisation simple doit être utilisée en aéronautique, afin d'essayer d'évaluer la charge de travail des équipages, d'aider à sa répartition et de détecter le seuil maximum où l'homme ne peut plus faire face. Car c'est la répétition de ces expériences qui pourra peut-être permettre la quantification de la charge de travail grâce à l'étude de la variabilité cardiaque.

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SUJET LEM...		FREQUENCE CARDIAQUE			VARIABILITE CARDIAQUE		
N° de Vol	ILS	Nb	Moyenne	Ecart type	Nb	Moyenne	Ecart type
	1						
	2	31	79,90	0,07	30	4,33	0,30
47	3	24	78,58	0,24	23	3,73	0,31
	4	27	79,44	0,21	24	5,29	0,29
(1)	5	12	77,58	0,37	13	4,92	0,30
		Total	78,87	0,22		4,56	0,30
	1	44	83,56	0,60	43	3,06	0,29
	2	40	81,85	0,48	39	2,38	0,25
50	3	38	80,81	0,20	37	3,59	0,27
	4	37	80,27	0,16	41	3,90	0,16
(3)	5	39	80,33	0,14	38	3,63	0,27
		Total	81,36	0,31		3,31	0,24
	1	42	80,16	0,23	42	3,59	0,42
	2	46	77,80	0,25	46	3,56	0,29
52	3	46	79,76	0,19	45	3,17	0,31
	4	49	79,55	0,20	48	3,29	0,41
(4)	5	47	79,65	0,83	46	2,82	0,23
		Total	79,38	0,34		3,28	0,33
	1	37	77,83	0,38	36	4,25	0,33
	2	38	77,34	0,37	37	4,72	0,37
58	3	40	77,72	0,36	40	4,40	0,43
	4	39	77,64	0,32	39	4,41	0,31
(5)	5	44	77,29	0,39	43	4,16	0,28
		Total	77,56	0,36		4,38	0,34

TABLEAU N° 1

SUJET MAU...		FREQUENCE CARDIAQUE			VARIABILITE CARDIAQUE		
N° de Vol	ILS	Nb	Moyenne	Ecart type	Nb	Moyenne	Ecart type
	1	79	81,08	0,88	78	9,01	0,44
	2	66	84,93	1,39	66	8,15	0,45
45	3	70	81,12	1,19	69	9,13	0,52
(1)	4	74	78,29	0,63	71	10,26	0,60
	5	76	76,90	1,04	74	11,47	0,57
		Total	80,46	1,02		9,60	0,51
	1	35	81,82	2,90	35	8,77	0,81
	2	33	87,03	2,55	33	8,12	0,79
53	3	32	84,68	2,77	31	9,48	0,97
(2)	4	34	92,41	3,40	33	7,90	0,94
	5	27	81,51	2,35	25	10,12	0,99
		Total	85,49	2,79		8,87	0,90
	1	34	77,52	1,67	34	10,76	0,78
	2	31	76,96	1,73	31	11,90	0,99
55	3	34	76,91	2,31	33	12,21	1,12
(3)	4	33	74,42	1,91	33	10,81	0,89
	5	30	69,60	1,59	30	13,00	0,83
		Total	75,08	1,84		11,73	0,92
	1	42	97,73	3,37	41	4,58	0,49
	2	45	88,64	2,42	44	5,61	0,56
59	3	40	92,00	3,01	39	5,71	0,67
(4)	4	40	84,95	1,82	38	6,63	0,56
	5	43	80,62	1,75	43	7,72	0,72
		Total	88,78	2,47		6,05	0,60
	1	25	81,28	2,55	25	11,00	0,92
	2	33	80,24	2,64	33	8,81	0,81
61	3	35	76,22	1,86	35	9,31	0,83
	4	32	71,53	1,36	31	11,64	0,73
(5)	5	33	67,96	1,25	32	13,78	0,91
		Total	75,44	1,93		10,90	0,84

TABLEAU N° 2

SUJET CAS...		FREQUENCE CARDIAQUE			VARIABILITE CARDIAQUE		
N° de Vol	ILS	Nb	Moyenne	Ecart type	Nb	Moyenne	Ecart type
54 (1)	1	34	89,44	1,31	34	4,23	0,38
	2	31	84,58	0,93	30	5,43	0,43
	3	36	83,83	0,80	35	6,05	0,66
	4	36	81,36	0,37	36	5,72	0,38
	5	35	80,82	0,28	34	6,76	0,43
		Total	84,00	0,73		5,63	0,45
56 (2)	1	39	103,71	1,34	39	2,30	0,25
	2	37	99,81	1,13	37	3,18	0,36
	3	37	93,78	1,19	36	2,91	0,31
	4	34	90,50	0,92	34	4,00	0,36
	5	35	86,68	0,71	34	3,91	0,30
		Total	94,89	1,05		3,26	0,31
57 (3)	1	24	86,87	1,17	24	4,83	0,61
	2	29	92,72	1,01	27	3,07	0,34
	3	33	88,00	0,98	33	4,00	0,33
	4	25	85,92	1,07	24	4,20	0,34
	5	34	85,05	0,86	33	4,48	0,44
		Total	87,71	1,01		4,11	0,41
60 (4)	1	43	76,60	0,59	39	7,58	0,39
	2	41	75,46	0,68	39	7,48	0,43
	3	44	78,59	0,29	43	6,79	0,35
	4	44	77,40	0,53	43	7,30	0,38
	5	46	75,67	0,76	45	7,48	0,42
		Total	76,74	0,57		7,32	0,39

TABLEAU N° 3

SUJET LOR...		FREQUENCE CARDIAQUE			VARIABILITE CARDIAQUE		
N° de Vol	ILS	Nb	Moyenne	Ecart type	Nb	Moyenne	Ecart type
	1	31	78,06	1,25	28	13,53	0,91
	2	37	77,40	1,36	38	11,39	0,74
44	3	43	77,76	1,08	40	11,20	0,84
(1)	4	47	77,51	1,08	47	12,97	0,84
	5	45	79,93	0,80	43	12,44	1,12
		Total	78,13	1,11		12,30	0,89
	1	45	113,97	1,89	46	3,63	0,56
	2	35	106,77	2,06	34	4,64	0,68
46	3	40	107,57	1,68	39	6,84	1,05
(2)	4	30	117,50	2,11	32	4,53	1,06
	5	35	105,71	1,52	35	6,20	0,76
		Total	110,30	1,85		5,16	0,82
	1	36	113,80	1,64	34	6,79	1,52
	2	45	107,71	1,09	43	6,39	0,88
49	3	44	104,11	1,08	43	6,97	0,84
(3)	4	44	97,20	1,26	45	7,66	0,68
	5						
		Total	105,70	1,26		6,95	0,98
	1	67	83,80	0,93	66	12,96	0,96
	2	49	82,24	1,18	49	11,85	1,02
51	3	48	85,31	0,80	47	8,40	0,76
(4)	4	45	89,42	1,41	44	8,29	0,81
	5	47	80,44	0,58	47	9,87	0,53
		Total	84,24	0,98		10,27	0,81

TABLEAU N° 4

PLANCHE N° 1

Date :

N° du vol :

Nom du Pilote :

Nature du vol :

Commentaires du Pilote sur la nature de la difficulté des essais (Etude Charge de travail)

PLANCHE N° 2

Date :

N° du vol : **N° de la passe :**

Nom du pilote :

Nature de l'essai :

Conditions atmosphériques :
noter la turbulence (1 nulle, 2 faible, 3 moyenne, 4 forte, 5 très forte)

Considérez-vous avoir atteint l'objectif de votre tâche ? OUI - NON

Estimez la difficulté de votre tâche :

0 minimum :
10 maximum :
5 correspondant à la difficulté limite normalement admise pour un atterrissage I.L.S. :

(selon l'échelle de Cooper qui vous a été fournie) :

Commentaires particuliers du Pilote :

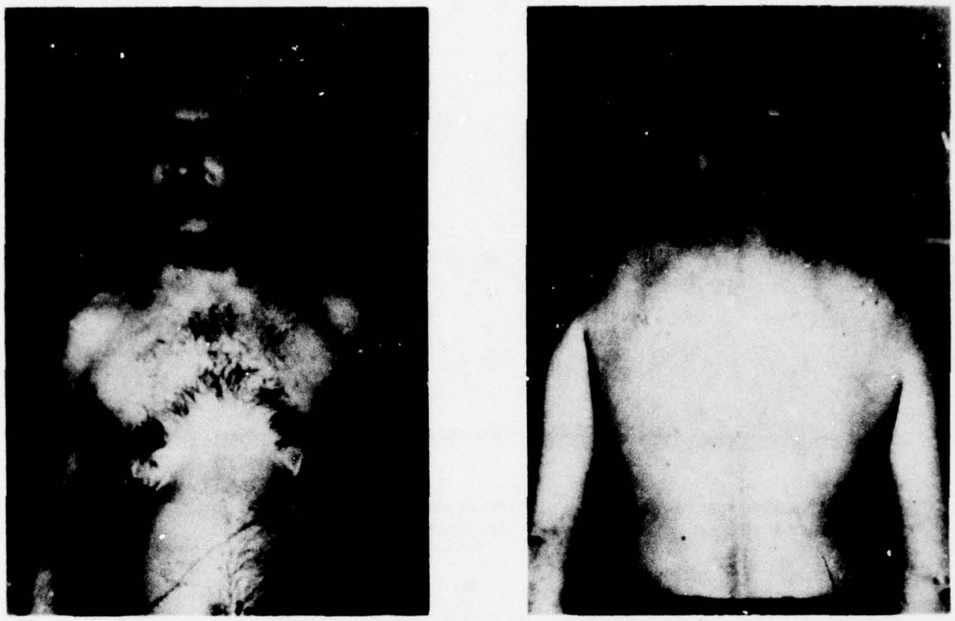

Fig. 1 : Emplacement des électrodes pour la mesure de la fréquence et de la variabilité du rythme cardiaque.

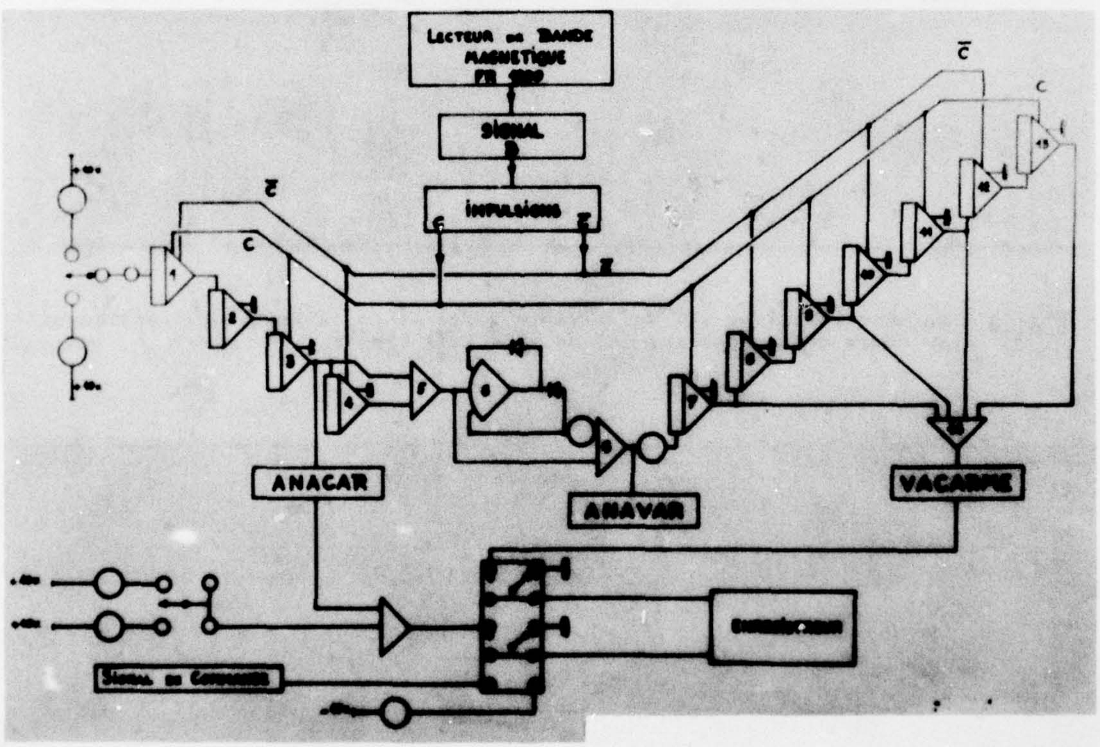

Fig. 2 : Diagramme d'analyse des paramètres cardiaques.

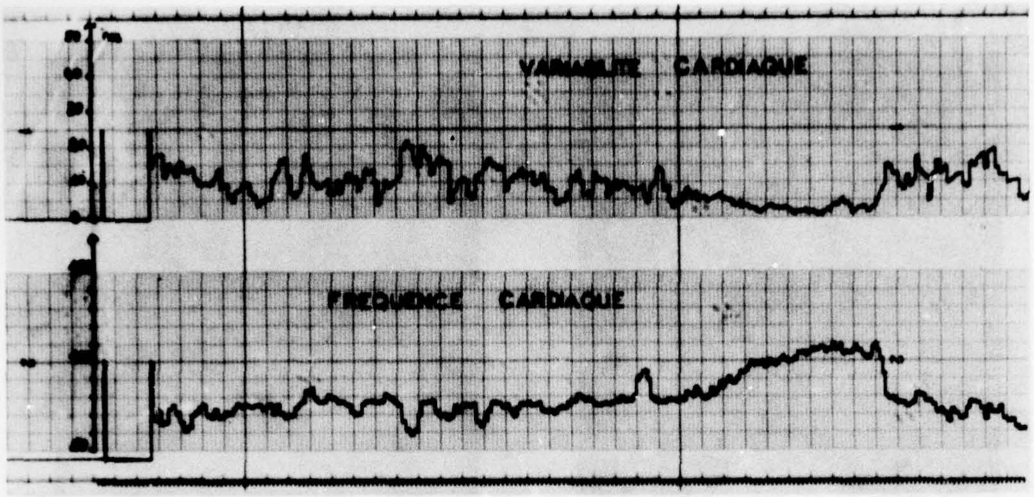

Fig. 3 - Enregistrement en vol de la variabilité et de la fréquence cardiaques au cours d'une approche ILS de type 3.

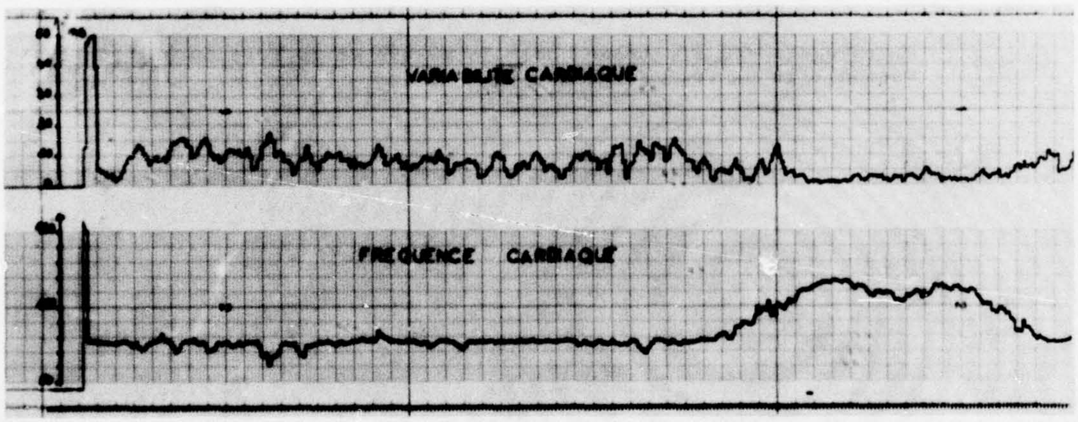

Fig. 4 - Enregistrement en vol de la variabilité et de la fréquence cardiaques au cours d'une approche ILS de type 4.

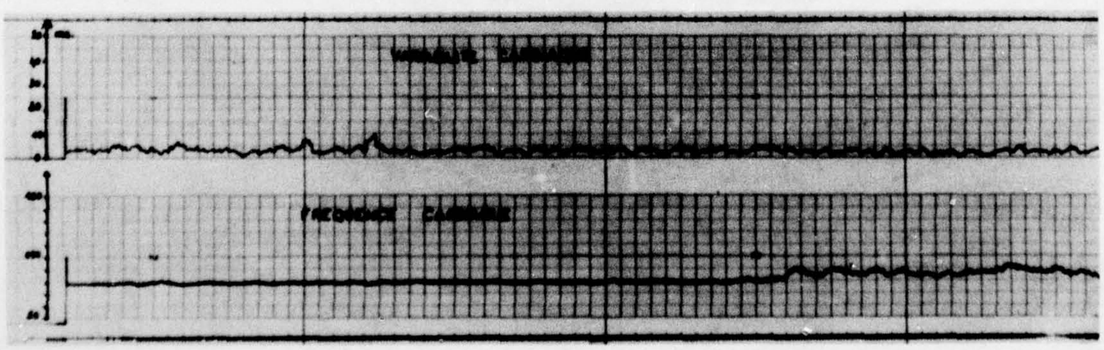

Fig. 5 - Enregistrement en vol de la variabilité et de la fréquence cardiaques au cours d'une approche ILS de type 3
(on remarque une variabilité pratiquement inchangée).

DISCUSSION

M.G.Sanders: The activity of psychologists should not be limited to the study of ratings or other subjective judgments. This is misleading since the major task of psychologists has been to analyse behavior.

To what extent are your data on variability indicative of differences in motor activity. This is only one aspect of load, and, consequently, variability of heart rate cannot be considered as a measure of "general" mental load. May I have your comments please?

B.Vettes: (1) Oui, l'aspect comportemental des sujets interrogés doit prendre une grande importance et le questionnaire doit toujours en tenir compte. J'ai d'ailleurs souligné la nature "optimiste" ou "pessimiste" des sujets interrogés, ce qui traduit bien une façon de comportement.

(2) Certes, le rythme cardiaque croît lorsque l'activité motrice augmente, mais, dans notre cas, où l'activité motrice est mineure et ne varie pratiquement pas, l'accroissement de la fréquence en corrélation avec une diminution de la variabilité cardiaque (phénomène constant) traduit bien une tâche intellectuelle perceptive.

K.H.Doetsch: There is in existence an improved Cooper-Harper scale (an AGARD document) that is supposed to make it easier for pilots to translate their opinion into numerals than the Cooper Scale quoted in the paper.

B.Vettes: Je suis parfaitement au courant de l'existence de cette échelle, qui a d'ailleurs été conçue par un ingénieur du C.E.V., en accord avec nos pilotes, et admis par l'AGARD. Dans notre expérimentation le questionnaire proposé provenait d'un organisme étranger au CEV (psychologues de l'Université).

A STUDY ON PILOT'S WORKLOAD IN HELICOPTER OPERATION UNDER SIMULATED IMC EMPLOYING A FORWARD LOOKING SENSOR

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SUMMARY

Various measures of pilot workload are known which are presently applied to human engineering investigations. It is difficult, however, to find a measure which has proved to be universally applicable and adequately validated. Measures tailored to a specific application may be less flexible but can provide relevant and sufficient information on pilot workload. This is demonstrated by referring to experiments with advanced helicopter displays which were tested in flight.

LIST OF SYMBOLS

A	- mechanical work
IMC	- instrument meteorological conditions
m	- mass
M	- torque
r	- product-moment-coefficient of correlation; distance
rms	- root mean squared
t	- time
T	- duration of test
v	- velocity
VFR	- visual flight rules
VMC	- visual meteorological conditions
α	- angle of rotation
φ	- bank angle
Θ	- moment of inertia
ω	- angular velocity
ω_x	- roll rate
ω_y	- pitch rate
ω_z	- yaw rate

1. INTRODUCTION

Some years ago an AGARD Working Group on "V/STOL Displays for Approach and Landing" surveyed the measures of pilot's performance and workload currently applied to the investigation of displays. 32 institutions in 5 NATO countries were interviewed and the result showed that approximately 50 more or less different measures were in use. Even more measures were developed in the following years with the effect that the chance to find two different experiments in which identical workload measures were applied became progressively smaller. Though a uniform measure of workload would be one of the most important prerequisites to gain a higher degree of economy of human engineering investigations there are definite limitations to achieve this goal. Some aspects of workload measurement are discussed, therefore, and some workload measurements and the results are presented by referring to flight tests with advanced displays for helicopter.

2. PHILOSOPHIES OF WORKLOAD MEASUREMENT

Two major philosophies seem to exist in the development of workload measures [1] . In short, one is

- to select from the variety of possible measures the most promising one
- to validate it to a high degree in order to make it applicable to a number of experimental conditions
- to apply it to this variety of experimental conditions and to rely on it until more efficient measures may be found

There is a high risk, of course, not to proceed any further than step 2 - the validation. The other is

- to record simultaneously measures in the fields of control technology, psychology, physiology and subjective ratings
- to form different hypotheses about the meaning and significance of these measures with respect to the particular experiment
- to find a decision within a group of interdisciplinaryly trained specialists which hypothesis may be the most acceptable one

Of course, this philosophy has deficiencies, too. Questions arise, for example, who is a specialist and who ist not? why measure heart rate, respiratory rate, respiratory volume, carbon dioxide production, oxygen consumption, work rate and systolic blood pressure simultaneously if all these measures are linearly correlated within the range of interest [2] ? what is the relative importance of the individual measures? and so on. But it also has definite advantages compared to the philosophy mentioned earlier:

i) workload may be assessed on a basis much broader than represented by a single criterion
ii) the risk of over-emphasizing one particular measure is reduced by the often counterbalancing effect of other measures
iii) the weight which was assigned to each individual measure simply may be changed if a better understanding of the measures and their behaviour has developed without the need to run the experiment again.

3. ASSESSMENT OF PILOT WORKLOAD

The large number of workload measures one can think of most often diminishes rapidly if these measures are going to be applied to a real case. In practice there are numerous limitations as, for example, limited time available for the experiment, less well trained test subjects, laboratory methods which will not work in an airborne environment, flight tests to be made in remote areas without ground support and so on. Anyhow, some insight into pilot workload can be gained even under these limitations which will be demonstrated by referring to two rather different practical cases. In both cases advanced displays for helicopter and their impact on pilot workload had to be investigated in flight in a Bell UH-1D helicopter.

3.1 CASE 1

In this case the layout of a head-up display had to be investigated which was designed to assist pilot/gunner cooperation in a tank attack helicopter [3] . In this experiment the gunner had to find and to track a target by means of a steerable electro-optical sight. But to enable the gunner to release a guided weapon the pilot had to align the helicopter longitudinal axis with the line of sight of the gunner's sight and to maintain this position with "wings" level for some period of time within close limits. In order to assist the pilot in his task a head-up display was installed at the pilot's seat. Two head-up display formats C and D were investigated. Both displays presented about the same information in different formats with the exception that an additional lateral steering command was presented in display D. This indicator provided the pilot with a turn right/turn left director which theoretically would allow an optimum alignment of the helicopter with the target.

The working conditions of this experiment were:

i) 15 pilots were available for flight tests. None, however, had experience with a head-up display.
ii) A very limited time only was available for the experiment.

It was decided, therefore, to concentrate on subjective ratings in order to get some information on factors affecting pilot workload rather than taking objective measurements for which a large variability was expected. Rating scales were employed for this purpose having a choice of 5 positions to represent the pilot's opinion with respect to an item in question. For various and well-known reasons [4] no attempt was made to calculate means, standard deviations etc. for the ratings recorded. Rather the number of ratings on the left side from the neutral center of the scale was compared to the number of ratings on the right side. The binomial test [5] was applied which showed whether a possible difference of both numbers occured by chance only or whether there was a significant difference ($p < 0.05$) indicating a dominance of ratings on one side of the scale.

In order to demonstrate some of the outcomes 4 typical items in question and the ratings obtained are shown in figures 1 and 2. The first two questions (fig. 1a, b) were related to the availability of a torque and a bank indicator. Missing information is directly related to pilot workload and figures 1a, b show that, for example, a missing torque indicator is a significant factor while a high accuracy below ± 10 degrees of the bank indicator seems not to be a significant factor in this respect. However, the latter result is not statistically significant. This depends, of course, on the type of question and on the range of the rating scale. It was observed quite generally that a dominance of ratings on the left side of the scales, i.e. favouring an item, almost always was statistically significant which was not the case if there was a tendency to mark positions on the right side of the scales, i.e. considering an item unimportant.

Quite different distributions of ratings were obtained if the question was directed toward the layout of the new display relative to conventional instruments. Of course, the layout of displays affects pilot workload, too, but answers given in this respect are often more subjectively motivated than by the operational requirements. The two corresponding distributions of ratings are shown in figs. 2a, b. Though both distributions have no statistically significant dominance of ratings on either side of the scale there is a tendency to concentrate ratings on the center (fig. 2a) or on the extreme right and left positions of the scale (fig. 2b). In the first case there is a tendency not to favour the electronic displays (Displays C and D) nor the conventional instrument with respect to their layout. But in the second case there is a difference of opinions, one favouring the electronic displays and another favouring the conventional instrument. The layout of the bank indicator, therefore, was not considered a major factor affecting pilot workload. But the second case gives rise to the assumption that pilot workload is affected sensitively by the layout of the torque indicator. The redesign of the layout of this indicator, therefore, was given a high priority.

A major difference between displays C and D was the availability of a lateral steering command in display D which assisted the pilot in aligning the helicopter longitudinal axis with the line of sight of the gunner's sight. The ratings showed that the pilots considered the lateral steering command highly desirable (fig. 3). But because of the limited time available for the experiment the pilots could not be trained to use this indicator to full advantage. By means of a simulation of the total system including the pilot an rms error of the angle between the helicopter longitudinal axis and the line of sight of the gunner's sight of 30.6 mrad was predicted for a given time using display C presenting no lateral steering command. The pilots indeed achieved an error of 32.6 mrad in flight (table 1). For display D presenting the lateral steering command an rms error of 7.5 mrad was predicted but the pilots could reduce the rms error in flight to 29.1 mrad only. An extended period of training would have been required to achieve a higher performance. But more important, pilot workload was predicted to be much higher, too, raising from 33 mrad to 83 mrad for the rms error of pedal movements (+ 152 %) and from 12 to 70 (+ 483 %) for the pedal

reversals. A less considerable improvement of performance which could be achieved was predicted, therefore, for display D than theoretically possible because in flight the pilot is burdened by more than the alignment process alone.

3.2 CASE 2

In the second case a head-down display was investigated which presented a combination of the terrain ahead of the helicopter and electronicly generated instrument displays on a monitor screen [6] (fig. 4). The purpose of this experiment was to compare ordinary daylight VFR flights to flights in which the pilots employed this display as the only flight instrument with respect to flight performance and pilot workload. The experiment was part of a larger program to investigate possible benefits of an integration of a forward looking electro-optical sensor into a helicopter avionics system.

The working conditions of this experiment were - quite different from case 1 - as follows:

i) 2 well-trained pilots were available who had long-term experience with the display
ii) an extended period of time was available for the experiment.

It was decided, therefore, to take objective measurements because a low variability was expected. The interpretation of the results was supported by conclusions drawn from pilot interviews. Three areas were of particular interest with respect to an assessment of pilot workload:

a) Coordinated flying

Helicopter pilots are trained to fly coordinated with respect to bank and yaw, i.e. to keep the slip indicator centered. Less coordinated flying may be caused by turbulences but also by a detraction of pilot's attention from this task if other tasks are becoming more demanding. Therefore the squared product-moment coefficient of correlation between bank angle φ and yaw rate ω_z was determined because r^2_{φ,ω_z} represents the proportion of coordinated flying, i.e. the proportion of the total variation of yaw rate ω_z which is correlated with a variation of bank angle φ . The parameter r^2_{φ,ω_z} may serve as an indirect measure then to indicate a variation of pilot's attention in this respect if other influencing factors as, for example, turbulences or a variation of torque are less appearing.

b) Manual stabilization of the helicopter in its axes

In an unstabilized helicopter pilot workload may be considered related directly to the mechanical work A which is controlled by the pilot in order to stabilize the helicopter in its axes. An elementary unit of work may be calculated as (see appendix)

$$dA = d\left(\frac{\Theta}{2}\omega^2\right)$$

Θ - moment of inertia
ω - angular velocity

And for Θ = const. the mean value of A with respect to time is

$$\bar{A} = \frac{\Theta}{2}\left[\frac{1}{T}\int_0^T \omega^2\, dt\right]$$

T - duration of test

But the term

$$\frac{1}{T}\int_0^T \omega^2\, dt$$

is equal to the squared rms-value of ω which can be measured in flight and which leads to

$$\bar{A} = \frac{\Theta}{2}\,\omega^2_{rms}$$

Thus for Θ = const. and for nearly constant friction loads (which can be assumed for a nearly uniform progress of flights which in turn can be examined by means of the recorded flight parameters) and for $\bar{\omega} \approx 0$, ω^2_{rms} may be considered a relative measure to assess pilot workload produced by the stabilization task.

c) Average bank angle

An average bank angle different from zero indicates that the helicopter constantly banks to one side. Pilots are trained to take corrective action in this case. But experience shows that a constant bank angle which may be small and unnoticed by the pilot occures when the pilot's attention is absorbed by more demanding tasks than flying "wings level".

Table 2 presents a comparison of the three measures for flights under VMC and for flights under simulated IMC employing the display. It can be seen that an increase of $\omega^2_{x,rms}$ by a factor of 29 and an increase of $\omega^2_{y,rms}$ by 25 % indicate much higher pilot workload when flying under simulated IMC. This may be because a qualitative assessment of pitch and roll and their variation is much easier for the pilots under VMC than it is by means of the display. Increased pilot workload is also indicated by the measure of coordinated flying r^2_{φ,ω_z} which drops from 52 % under VMC to 39 % under simulated IMC. A major cause may be the higher and more unsteady activity in roll ($\omega^2_{x,rms}$) under simulated IMC already mentioned. It is interesting to note that the pilots also allowed an increase of the average bank angle φ by 80 % when flying under simulated IMC.

Table 3 presents a comparison of the three measures obtained from flights over level and undulated terrain irrespective of the flight conditions, i.e. VMC or simulated IMC. It can be seen that an increase of $\omega^2_{z,rms}$ by 41 % and $\omega^2_{y,rms}$ by 14 % reflect higher pilot workload caused by much more turns to be flown and by the varying slope of the terrain.

Table 4 presents a comparison of measures obtained from flights under simulated IMC over well-known and unknown courses. It can be seen that an increase of $\omega^2_{z,rms}$ by a factor of 2.6 marks higher pilot workload because of much more turns to be flown on the unknown courses. But while the magnitude of $\omega^2_{x,rms}$ dropped by a factor of 43, r^2_{φ,ω_z} reached a maximum of 0.54 compared to all other flights. This demonstrates that the pilots flew coordinated with respect to roll and yaw but in gentle turns only because the danger to lose orientation on an unknown course is much greater than on a well-known course which in each case would have stopped the experiment.

4. CONCLUSIONS

It is anticipated that even in the long run it will be questionable whether a single and universally applicable measure of pilot workload will be found. Measures tailored to a specific application may be less flexible but may yield results significant in both a statistical and operational sense on a level which makes them useful for those who specify, develop and operate man-machine systems. This has been demonstrated by referring to a practical case. Though the measures presented may be not applicable elsewhere it is hoped that their presentation may stimulate corresponding work in other areas where a measure of workload is needed.

5. REFERENCES

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4. J.D. McDonnell, Pilot Rating Techniques for the Estimation and Evaluation of Handling Qualities. Air Force Flight Dynamics Laboratory, Wright Patterson AFB, Ohio, AFFDL-TR-68-76 (1968).

5. S. Siegel, Nonparametric Statistics for the Behavioural Sciences. McGraw-Hill, Tokyo (1956).

6. R. Beyer, Untersuchung einer kombinierten Darstellung von Umweltbild und Instrumentenanzeigen in einem Hubschrauber Bell UH-1D. DFVLR IB-153-76-11 (1976).

Appendix

Control of the helicopter in its axes

In an unstabilized helicopter pilot workload may be regarded as directly related to the (mechanical) work A required for a rotation of the vehicle in its axes:

$$A = M\alpha$$

M - torque

α - angle of rotation

The total amount of work may be calculated as the sum of units of work dA:

$$dA = M\,d\alpha = m\frac{dv}{dt}\,r\,d\alpha$$

m - mass

v - tangential velocity at distance r from the center of rotation

$$\frac{d\alpha}{dt} = \omega \qquad dv = r \cdot d\omega \qquad \Theta = mr^2$$

ω - angular velocity

Θ - moment of inertia

$$dA = mdvr\omega = mr^2\omega d\omega = d\,(mr^2\,\frac{\omega^2}{2}) = d\,(\frac{\Theta}{2}\,\omega^2)$$

For Θ = const. the average value of A may be calculated:

$$\bar{A} = \frac{\Theta}{2}\left[\frac{1}{T}\int_0^T \omega^2\,dt\right]$$

T - duration of test

And for

$$\omega^2_{rms} = \frac{1}{T}\int_0^T \omega^2\,dt$$

it is

$$\bar{A} = \frac{\Theta}{2}\,\omega^2_{rms}$$

For Θ = const. and for nearly constant friction loads (to be assumed for a nearly uniform progress of flights which can be examined by means of the flight parameters) and for $\bar{\omega} \approx 0$ the value of ω^2_{rms} may be taken as a relative measure for pilot workload caused by the control of the work A required to control the helicopter in its axes.

What do you think about the availability of an accurate indication of bank angles below 10 degrees in head-up displays C and D?

```
                                                                  D
                                                                C D
                                                                C D
                                                                C D
                                                                C D
                                           C              D     C D
              D          C               C D            C D     C D
required     C D--------C D-------------C D------------C D-----C D    unimportant
              0          0               0              0       0
```

Figure 1a

What do you think about the availability of a torque indicator in head-up displays C and D?

```
              C D
              C D
              C D
              C D
              C D
              C D
              C D
              C D
              C D
              C D
              C D
              C D                        C D
imperative    C D----------0------------C D------------0-------C D    not required
               0                         0                      0
                  SIGN.
```

Figure 1b

Figure 1: Distribution of ratings obtained for head-up displays C and D. SIGN. = Significant dominance of ratings on one side of the scale ($p < 0.05$).

What do you think about the layout of the bank indicator in head-up displays C and D compared to the conventional instrument?

```
                              D
                              D
                            C D
                            C D
                            C D
                            C D
               C            C D          D
               C D          C D        C D          C D
Display C resp. D   C D----------C D----------C D----------C D----------C D   Conventional instru-
is easier to read    O            O            O            O            O    ment is easier to
                                                                              read
```

Figure 2a

What do you think about the layout of the torque indicator in head-up displays C and D compared to the conventional instrument?

```
                      D
                      D                                                 C D
                    C D                                                 C D
                    C D          C                          D           C D
                    C D          C            C           C D           C D
Display C resp. D   C D----------C D----------C D----------C D----------C D   Conventional instru-
is easier to read    O            O            O            O            O    ment is easier to
                                                                              read
```

Figure 2b

Figure 2: Distribution of ratings obtained for head-up displays C and D.

What do you think about the availability of the lateral steering command in head-up display D?

```
                     D
                     D
                     D
                     D
                     D
                     D            D
                     D            D
                     D            D
                     D            D            D
very useful          0------------0------------0------------0------------0          unimportant
                        SIGN.
```

Figure 3: Distribution of ratings obtained for head-up display D. SIGN. = Significant dominance of ratings on one side of the scale ($p < 0.05$).

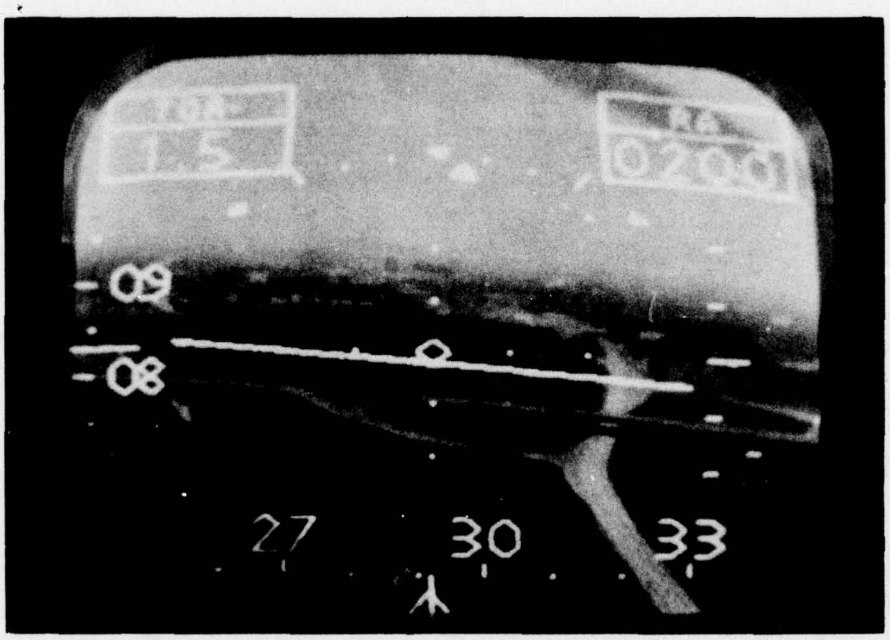

Figure 4: Combination of instrument displays and an image of the terrain ahead of the helicopter in a head-down display.

rms error of alignment (mrad)			
Flight Test		Simulation	
Display C	Display D	Display C	Display D
32.6	29.1	30.6	7.5
rms error of pedal movements (mrad)		33	83
number of pedal reversals		13	70

<u>Table 1:</u> Comparison of the alignment of the helicopter with a target employing head-up displays C and D, the latter presenting a lateral steering command.

Parameter	Dimension	VMC	Simulated IMC	Error Probability
φ	deg.	-1.5	-2.7	< 1 $^{o}/oo$
$\omega^2_{x,rms}$	$(deg/s)^2$	0.06	1.72	"
$\omega^2_{y,rms}$	"	0.73	0.91	"
$\omega^2_{z,rms}$	"	1.02	1.17	-
r^2_{φ,ω_z}	-	0.52	0.39	< 1 $^{o}/oo$

<u>Table 2:</u> Comparison of parameter means obtained from flights on a known course under VMC and simulated IMC using the head-down display.

Parameter	Dimension	Level Terrain	Undulated Terrain	Error Probability
φ	deg	-2.2	-2.1	-
$\omega^2_{x,rms}$	$(deg/s)^2$	0.76	1.02	-
$\omega^2_{y,rms}$	"	0.76	0.87	< 5 %
$\omega^2_{z,rms}$	"	0.91	1.28	< 2 $^o/oo$
r^2_{φ,ω_z}	-	0.46	0.46	-

Table 3: Comparison of parameter means obtained from flights over level and undulated terrain on a known course irrespective of the flight conditions, i.e. VMC or simulated IMC using the head-down display.

Parameter	Dimension	Known Course	Unknown Course	Error Probability
φ	deg	-2.7	-3.4	-
$\omega^2_{x,rms}$	$(deg/s)^2$	1.72	0.04	< 2 %
$\omega^2_{y,rms}$	"	0.91	1.06	-
$\omega^2_{z,rms}$	"	1.17	3.10	< 2 %
r^2_{φ,ω_z}	-	0.39	0.54	< 5 %

Table 4: Comparison of parameter means obtained from flights under simulated IMC on known and unknown courses using the head-down display.

DISCUSSION

D.W.Jahns: You indicated that you went to subjective measures because of all the natural tendencies in the field of not being able to qualify the areas you might be interested in. You indicated that the subjective ratings were discriminated as well, I am wondering whether you might not agree that subjective variability and reliability tend to be somewhat larger than what we normally find in our objective measures. So, to draw conclusions regarding display design, from objective measures where we don't have a measure of the reliability although we are fully aware that sometimes we have to rely on it because it's the only thing we can get. But I would submit that at all times we should try to augment it by field test once we have established new designs for these displays. The same thing really applies to your comment that the slide where the simulations predicted at 7.5 milliradient and the test actually show 29 and that this may have been done into the training. The trainings effect could also be such that it would not discriminate between the two techniques either. So what could you expect from a training type approach to display design introducing workload.

R.Beyer: Well the point I would like to make is that of course one can't think and vary a leveled experiment and we would also like to have better experimental conditions; but, in first case, where we had only a week to give some insight into the head-up display, the only measure which was available was the subjective ratings of the pilot. So we had no other means to get any information, it was not possible to instal any sensor into the helicopter and so forth. Once we have obtained these ratings, then we have to test the outcomes whether we have a dominance on one side of the scale. Of course there is a variability and the outcomes might be somewhat different if we have a large period of training and so forth. But in this case, I think it was the optimum solution because we obtained statistically significant results, we also showed some operation relevance. But of course this is no current basis for any display development and one has to plan an appropriate experiment then to go into the details. But for this situation and this was the point I wanted to make it was the best method to obtain results under these conditions. Now the other thing, the simulations, of course, it is not very brilliant to present results we admit that you predict a high performance of 7,5 miliradians and in flight the pulse achieves only 30 milliradians. But again the point is: we predict what could be theoretically possible, but we excluded the operational environment in that, we simulated only this alignment task and not the real mission, so, what we predict then theoretically is possible to get an improvement of about factor four, but in practice we would assess these improvements in the order of 2, and this is now the basis for an experiment in this direction. So, I would recommend not to hesitate to apply these methods, because they are economic in order to set up a larger experiment later on rather than go into a large experiment without any findings of this kind.

Discussion between M.A.Lees and R.Beyer cannot be read because recorder too bad. Apologies of the editor.

AIRCREW FATIGUE IN NONSTOP, TRANSOCEANIC TACTICAL DEPLOYMENTS

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SUMMARY

The central issue addressed by this study was operational effectiveness following long-range deployment. Stress and fatigue were evaluated in F-4D crews before and after flying nonstop, transoceanic deployments from New Mexico to Germany and return. The measurement battery consisted of subjective fatigue ratings, self ratings of fitness to fly, sleep logs, and biochemical analyses of urine samples for norepinephrine, epinephrine, 17-hydroxycorticosteroids, urea, sodium, and potassium. The magnitude and the consistency of behavioral and physiological changes indicated the occurrence of mild fatigue immediately after both flights. The fatigue was acute and was ameliorated by one uninterrupted sleep period.

INTRODUCTION

Nonstop, long-range deployment imposes unique stresses upon tactical fighter crews and, therefore, constitutes an area of special biomedical concern. Prominent among the deployment stresses are disturbances in sleep and heavy mission workloads. At the request of the USAF Tactical Air Command, a study of aircrew stress and fatigue associated with nonstop, transoceanic deployment was conducted by the Crew Performance Branch, USAF School of Aerospace Medicine (USAFSAM). The objectives of the study were: (1) to quantify the magnitude of psychophysiologic disruption due to deployment, and (2) to determine the time course of recovery. The central issue was reduced fitness to fly, with its concomitant compromises in flying safety and operational effectiveness. Operation Crested Cap, an annual NATO exercise, served as a vehicle for the study. In support of Crested Cap 75, F-4D crews of the 49th Tactical Fighter Wing, Holloman AFB, New Mexico, flew nonstop to Hahn AB, Germany, on 6 September 1975, and returned nonstop to Holloman AFB on 6 October 1975.

METHOD

Two study periods were employed. They centered on the deployment from New Mexico to Germany (25 August-11 September 1975) and the return deployment (redeployment) back to New Mexico (2-9 October 1975). Each of the study periods consisted of a predeployment phase, a one-day flight phase, and a post-deployment recovery phase. The dates and days comprising each phase are presented in Table I. Data were not collected on the 19th through the 38th day (12 September-1 October 1975).

Deployment takeoff from Holloman AFB occurred during the evening of the 12th day (5 September). Four cells of four aircraft each departed between 2100 and 2300. This takeoff time was determined by the desirability of arriving at Hahn AB at approximately 1600 local German time. The time differential between Holloman AFB and Hahn AB is eight hours and the airborne deployment time was 11-12 hours. Days 12 and 13 were each less than 24 hours for the crews due to the eastward travel. In an attempt to compensate for the evening takeoff time, crewmen were encouraged by their commanders to remain awake the night of 4 September and were required to report to a holding barracks at 0600 the morning of 5 September, where they were provided sleeping quarters until being released at about 1600 for preflight preparation. The success and usefulness of this procedure will not be evaluated in this report. A wide range of sleeping behaviors was observed during the 24 hours preceding deployment takeoff. Redeployment takeoff occurred between 0900 and 1100 local German time on the 43rd day (6 October) and, therefore, followed a normal night's sleep; arrival at Holloman AFB was between 1400 and 1600 New Mexico time. Both the Hahn AB takeoff and the Holloman AFB landing occurred on day 43, which was a 32-hour day for the crewmen because of the westward travel. Each deployment required six air-to-air refuelings.

The crew of an F-4D is comprised of a pilot and a weapon system officer (WSO). Ten pilots and ten WSOs of the 8th Tactical Fighter Squadron participated in the study. The crewmen ranged in age from 25 to 32 years. Total flying hours ranged from 475 to 2400; flying hours in the F-4, 65 to 1700. Six of the crewmen had participated previously in one or two transoceanic deployments. The measurement battery was designed to meet the requirement for minimum interference with crew duties. It consisted of subjective fatigue ratings, sleep logs, self ratings on a modified Cooper-Harper scale on fitness-to-fly, and biochemical analyses of urine samples. Except for the fitness-to-fly ratings, an extensive data base has been developed for these measures in past USAFSAM studies on a wide range of flying activities (2, 5, 6, 7, 8, 9, 12, 13).

Subjective fatigue scores may range from 0 to 20 with lower scores indicating self ratings of greater fatigue. The flying fitness scale ranges from 0 to 10, with lower scores indicating self estimates of reduced fitness to fly. The urine samples were analyzed for (1) norepinephrine, an index of sympathetic nervous system activity, (2) epinephrine, adrenomedullary activity, (3) 17-hydroxycorticosteroids (17-OHCS), adrenocortical activity, (4) urea, protein catabolism, (5) sodium, and (6) potassium, indices of mineral metabolism. Urinary creatinine, a correlate of lean body mass, was used as an adjusting factor to minimize the influences of subject body size and age. Each urinary measure was expressed as a quantity per 100 mg creatinine (6). Moreover, precise timing of urine collections is unnecessary when creatinine-based ratios are employed. During the pre and post phases of both deployments, questionnaire data and urine samples were collected routinely by each crewman upon arising each morning. Flight day data were collected within two hours of landing after each transoceanic deployment. The urine samples were mixed with a preservative (1.6 normal HCl acid), immediately refrigerated, and frozen within 12 hours for later biochemical analyses.

RESULTS

The data from ten pilots and eight WSOs were submitted to analysis of variance, although some data were missing on some days. The data were excluded for two WSOs who did not take part in the redeployment. The .05 significance level was used for all mean comparisons. The behavioral measures were analyzed in original units, while the urine measures were analyzed using log transformation.

Behavioral measures. Where possible, the average of three days' data was used to improve the stability of the data. The mean values for the averages of days 3-5 and days 9-11 provided two estimates of baseline levels prior to deployment from Holloman AFB. The behavioral measures were unchanged between these two periods of time (Fig. 1). The crewmen slept a little more than eight hours per night and their subjective fatigue scores indicated they were well rested and alert. The flying fitness scores were consistently high, supporting the fatigue data.

The immediate postflight data, collected within two hours of landing in Germany on day 13, were compared with the mean baseline data of days 9-11. The 1600 Germany landing time corresponded to an 0800 New Mexico time. Thus this comparison was controlled for time-of-day, as the crewmen were still entrained to New Mexico time when the day-13 data were collected. A 34% decrease in subjective fatigue scores (indicating feelings of greater fatigue) and a 37% decrease in self estimates of flying fitness ($P < .001$ in both cases) were reported after the 12-hour transoceanic flight. No sleep occurred between departure from New Mexico on day 12 and arrival in Germany on day 13.

The crewmen slept an average of 12 hours during the first sleep period in Germany, a 41% increase over the baseline sleep times. Following this initial rest period (day 14) the subjective fatigue and fitness scores were 50% or more recovered. Days 16-18 represent the third, fourth, and fifth complete days in Germany. Comparing the average data of these three days with the days 9-11 baseline data, flying fitness was still significantly reduced ($P < .011$), although only by 6%. Hours slept and subjective fatigue were not statistically different from baseline.

Days 41-43a occurred after four weeks in Germany, with redeployment takeoff occurring in the midmorning of day 43. The average values for days 41-43a provided both an indication of adjustment to local German time and a baseline reference for the redeployment. Although the percent differences were small, significant reductions were present for subjective fatigue (6%, $P = .045$) and flying fitness (8%, $P = .005$) when compared to the days 9-11 baseline. Average hours slept were stabilized at about 8 hours per night.

Redeployment to New Mexico resulted in behavioral changes similar to those during deployment, although the magnitude of the changes was smaller. Using the mean values of days 41-43a as a baseline referent for comparison of the immediate postflight data collected on day 43b, subjective fatigue scores were reduced by 26% ($P = .011$) and flying fitness scores by 16% ($P = .006$). It should be noted that this postflight comparison, unlike that for deployment, was not controlled for time-of-day. The 1400-1600 arrival time in New Mexico corresponded to a local German time of 2200-2400. An increase in sleep time (24%) occurred for the first night back in New Mexico (day 44), lending credence to the immediate postflight fatigue and fitness scores. Redeployment recovery data could be collected for only three days; thus the average of days 44-46 is not directly comparable to the average of days 16-18 following deployment. However, recovery means of days 44-46 were compared with the baseline means of days 9-11, and there were no significant differences among the behavioral measures. Compared to baseline values, fatigue scores were only reduced 4% and fitness ratings were down 8%. The daily duration of sleep returned to 8-9 hours per night.

Urinary measures. The urinary data (Figs. 2 and 3) were grouped and compared in the same fashion as the behavioral data. In general, changes in the catecholamines, 17-OHCS, and urea complemented the behavioral changes over time. Sodium and potassium revealed more complex changes. Comparing the mean data for the two predeployment baseline intervals, there was only a single significant change over time. A crew position X time interaction ($P = .040$) in sodium output resulted from a low average value among WSOs on day 10. This interaction was likely a chance occurrence, and emphasized the need for averaging over days when possible.

Immediate postflight means on day 13 were significantly elevated for epinephrine ($P < .001$), 17-OHCS ($P < .001$), and urea ($P = .005$). Crew position X time interaction occurred for norepinephrine ($P = .035$) and potassium ($P = .024$), with pilot and WSO urinary values for these two measures being more similar immediately after flight than during baseline (Table II). For WSOs, norepinephrine and potassium output significantly increased ($P < .05$), while for pilots, an increase in norepinephrine output and a decrease in potassium output were not statistically significant. On day 14, after the first night's sleep in Germany, the urinary measures revealed varying degrees of recovery, except for potassium which was even more elevated.

Comparison of the mean values for deployment recovery days 16-18 with the mean baseline values for days 9-11 resulted in an overall effect for 17-OHCS output ($P = .011$) and a crew position X time interaction for potassium output ($P = .035$). Mean 17-OHCS output was lower during the deployment recovery interval. Pilot potassium values during recovery were considerably lower than their baseline, while WSO potassium values during recovery were moderately higher than their baseline.

Comparison of the deployment baseline means (days 9-11) with the redeployment baseline means (days 41-43a) indicated that mean overall urea levels were lower prior to redeployment than prior to deployment ($P = .016$). A crew position X time interaction ($P = .034$) occurred for norepinephrine, again reflecting a change for the WSOs with no concurrent change for the pilots. WSO norepinephrine output was greater during redeployment baseline in Germany than deployment baseline in New Mexico, but such comparison showed no difference for pilot norepinephrine output. Immediate postflight values were significantly elevated (days 41-43a vs. 43b) for all the urinary measures but potassium (norepinephrine, $P = .046$; epinephrine, $P < .001$; 17-OHCS, $P = .002$; urea, $P = .003$; sodium, $P = .002$). Redeployment recovery,

represented by the mean values of days 44-46 compared to the mean values of days 9-11, was evident for all the urinary measures but potassium, which was considerably elevated (P = .002). While the absolute mean values of norepinephrine output during redeployment recovery were very similar for pilots and WSOs, a significant crew position X time interaction (P = .012), similar to those already described, occurred for this comparison also. During redeployment recovery, WSO norepinephrine values were greater during redeployment recovery than during deployment baseline, while pilot norepinephrine values were very similar for these two intervals.

Crew position effects. While the temporal changes in the behavioral and urinary measures provide the relevant information for aircrew management during tactical deployments, the analyses also indicate some significant main effects relating to crew position. During the deployment baseline phase, subjective fatigue (P = .029) and flying fitness (P = .001) scores were consistently lower for pilots than for WSOs, although not so low as to require concern (Table II). Also during baseline, norepinephrine was higher for pilots (P = .035), and potassium levels approached being significantly (P = .051) higher for pilots. These baseline crew-position differences in norepinephrine and potassium contributed to the several significant interactions involving these measures when temporal comparisons were made between baseline and later phases. The overall crew-position differences were also present for fatigue, fitness, and potassium when deployment baseline means were compared with redeployment baseline means (P = .045, .002, and .049, respectively) and with redeployment recovery means (P = .033, .002, and .024, respectively).

DISCUSSION

The central issue addressed by this study was operational effectiveness following long-range deployment. While desynchronization and subsequent entrainment of circadian biorhythms following transmeridian flight have been well documented as contributing to feelings of malaise and fatigue (4, 10, 11, 17, 18), disrupted work and sleep schedules are factors of greater practical importance in a tactical deployment (1, 14, 15, 16). For the Crested Cap deployments, both the magnitude and the consistency of the behavioral and physiological changes indicated the occurrence of mild fatigue immediately after both flights. The fatigue was acute and was ameliorated by one uninterrupted sleep period. Operationally, this means that there are no major problems with deployments.

These findings are supported by prior USAFSAM studies of tactical operations. In an early study to appraise flying stresses, several urinary measures had significant elevations for pilots after they flew 6-hour overwater missions in F-100 and F-104 aircraft (13). The average physiological changes in pilots completing an 18-hour flight in F-4C aircraft were of small magnitude, and supported the subjective feelings of the crewmen who did not consider the flight difficult and did not feel unduly fatigued afterward (12). However, the urinary measure did differentiate between highly seasoned and less experienced pilots. FB-111 crewmembers (pilot and navigator) flew 8-hour missions as part of the aircraft's evaluation (8). Both subjective fatigue and urinary data demonstrated changes indicative of moderate stress and fatigue, particularly during the last four hours of the flights. Sleep on the night following the mission was 1.5 hours longer than the night before the mission, but returned to normal duration the second post-mission night. Unlike the present results, there were no differences related to crew position.

For the Crested Cap crewmen, a positive factor contributing to both the quantity and the quality of the first postdeployment night's rest and sleep was the late afternoon arrival in Germany. Allowing time for debriefing, billeting, and a meal, the tired crewmen were in immediate social synchrony with local German time. The crewmen did not have to try to sleep during hours of economic and social activity with the attendant distractions of sunlight and noise. Although there were some deviations, baseline values generally were recovered in the third to fifth day of postdeployment, and were unchanged four weeks later during the redeployment baseline phase. While one sample per day does not permit analysis of circadian patterns, these findings are in agreement with entrainment rates of 0.5-1.5 hours per day to a new time zone.

The redeployment flight appeared to be less stressful than the initial deployment flight. In addition to the already noted lack of correspondence between data sampling times before and immediately after the redeployment flight, a number of factors are important here. Redeployment departure from Hahn AB occurred in the morning after a normal night of sleep whereas deployment from Holloman AFB occurred in the evening after an atypical daytime sleep schedule. Although findings are contradictory on the relative disruptiveness of westward vs. eastward travel, travel to home base has often been found to be less disruptive than travel away from home (1, 10, 16, 17). Any combination of these factors may have influenced the findings in this study.

Crew position differences seldom have been found for any of the measures being reported. When they have occurred (2, 5, 6), the aircraft commander's responses have indicated relatively greater mission-related stress and fatigue than have the other crewmembers' responses. These findings have been interpreted as being related to the commander's substantial responsibility. The behavioral (subjective fatigue and flying fitness) and endocrine/metabolic (norepinephrine and potassium) differences between the F-4D pilots and WSOs in this study also indicated that greater levels of stress and fatigue were experienced by the aircraft commander (pilot). In this instance, however, the findings primarily resulted from statistical differences occurring during the baseline period preceding the deployment flight and were supported by similar differences during the redeployment baseline and recovery periods. There were no differences between pilots and WSOs immediately after completion of the deployments, as both crew positions reported depressed fatigue and fitness scores and generally elevated levels of urinary endocrine/metabolic output. The suggestion of chronically elevated levels of some of the urinary constituents in pilots is provocative and has been reported in an earlier paper from this laboratory (3). A probable cause is the substantially increased activity seen in any wing prior to a major exercise/test.

Summarizing, both deployments resulted in mild fatigue. A performance decrement has not been associated with this level of fatigue, though obviously there is a potential for performance degradation in exceptional situations such as high workload missions, extended periods of flying, or tasks requiring precision and speed. A commonsense management approach to deployment stress will help to alleviate the

problems resulting from a deployment from one continent to another. The focus by operational managers should be on ensuring a full night of sleep in a good sleeping environment, allowing a 12-hour block of time for this purpose. On the day following this sleep period, the crews will be ready for a full schedule of work.

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TABLE I

DATES OF DATA COLLECTION FOR CRESTED CAP 75

	Phase		
	Pre	Flight	Post
Deployment	25 Aug-5 Sep (NM: days 1-12)	6 Sep (G: day 13)	7-11 Sep (G: days 14-18)
Redeployment	2-6 Oct (G: days 39-43a)	6 Oct (NM: day 43b)	7-9 Oct (NM: days 44-46)

NM = Holloman AFB, New Mexico; G = Hahn AB, Germany

TABLE II

MEANS FOR MEASURES HAVING CREW POSITION EFFECTS

	Norepinephrine[1]		Potassium[1]		Subjective Fatigue		Flying Fitness	
	Pilot	WSO	Pilot	WSO	Pilot	WSO	Pilot	WSO
3, 4, 5	.276	.168	.482	.339	13.0	15.3	7.5	9.3
9, 10, 11	.360	.117	.528	.332	12.8	15.6	7.6	9.6
13	.453	.515	.463	.440	8.2	10.0	4.7	6.1
16, 17, 18	.241	.237	.351	.391	12.7	14.0	7.3	8.5
41, 42, 43a	.360	.463	.447	.477	12.2	12.7	7.4	8.2
43b	.515	.562	.469	.447	10.3	8.9	6.7	6.3
44, 45, 46	.373	.363	.601	.519	12.7	14.3	7.3	8.3

[1] Log_{10} Units

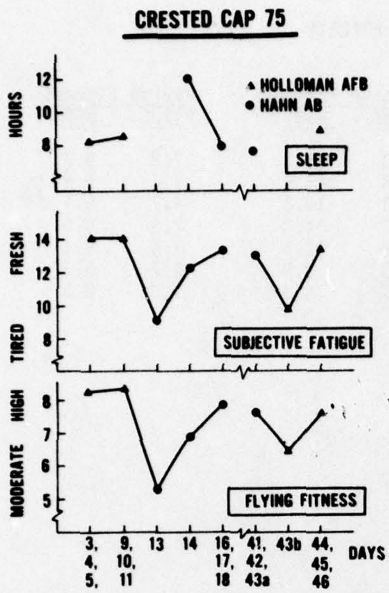

Figure 1. Mean values for hours slept, subjective fatigue ratings, and flying fitness scores during phases of deployment and redeployment in Crested Cap 75.

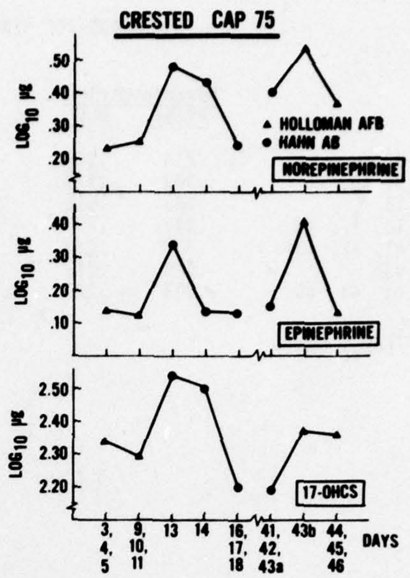

Figure 2. Mean values for urinary levels of norepinephrine, epinephrine, and 17-OHCS during phases of deployment and redeployment in Crested Cap 75.

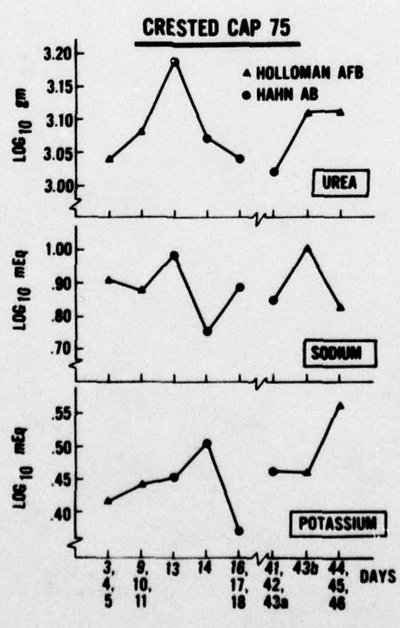

Figure 3. Mean values for urinary levels of urea, sodium, and potassium during phases of deployment and redeployment in Crested Cap 75.

DISCUSSION

C.A.Brictson: In view of the similarity of most of your biochemical results with subjective behavioral results, what are the advantages of collecting seemingly redundant results?

Were any extremes noted in the collection of biochemical data for any individual crew members?

B.O.Hartman: While there are several non-technical advantages to the biochemical battery, particularly in communicating with the biomedical community, the big advantage is that the biochemical measures provide information on the time course for recovery which is better qualitatively and quantitatively than the behavioral results.

H.C.Holloway: How did you correct for time of day effect in collecting urine samples?

B.O.Hartman: *Collections occurred within two hours of overseas deployment. This gives one confidence on the practical* effects.

Given the limit imposed by the operational environment, samples are reported at the time of collection at the place where they were collected.

Operational constraints (i.e. the requirement that the tests minimally disturb the working subjects) prevented a strict control of time of day effects).

H.C.Holloway: Dr. Hartman and this group is to be complimented on the report on crew position effects. This is extremely important data for the understanding of workload on a crew or an operational team.

ENDOCRINE - METABOLIC COST OF PILOTING F-104 G AIRCRAFT

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SUMMARY

Endocrine - metabolic responses to flight stress were studied in pilots participating in a training course on the F-104 G. All of them were experienced jet pilots, but had never flown the Starfighter before. During the course standardized 50-min missions of different loads had to be performed. By means of questionnaires the subjective estimates of instructor and student pilots with respect to the demand of the different types of missions were evaluated. Basing on this subjective rating, the missions were devided into groups of "low demanding" and "high demanding" flights; all night flights were taken together to a third group.

Responses to flying were evaluated by comparing pre- and postflight levels of blood constituents, including 11-Hydroxycorticosteroids (11-OHCS), Glucose (BG), Adenosinetriphosphate (ATP), Cholesterol (CH), and the activities of three cell enzymes (MDH, GOT, GPT). From the results the following conclusions were obtained:

1. Flying the F-104 G caused significant changes of most parameters. 2. The blood constituents differed in their work-load sensitivity: 11-OHCS, GPT, and MDH proved to be the most sensitive, GOT, Cholesterol, and ATP the most insensitive parameters for the load. BG does not seem to be an unequivocal variable to measure work-load. Reviewing the pertinent literature and comparing the figures with those obtained from studies with standardized stressors, the operational significance of the results are discussed.

INTRODUCTION

The increasing complexity of man-machine systems requires an adequate assessment of flight stress. Psychological as well as physiological parameters are necessary for a comprehensive appraisal of pilot's workload. It is the purpose of this paper to report on an investigation which was conducted with German Air Force military jet pilots. Blood concentrations of hormones, enzyme activities, and other metabolic constituents served as flight stress indicators.

METHODS

Metabolic endocrinological aspects of flight stress were studied in student pilots during a training course for the F-104 G. All of these were already experienced jet pilots. During this training course various missions with different workloads had to be performed. In order to evaluate the load questionnaires were given to the instructor and student pilots. Basing on the subjective rating the missions were divided into groups of "low demanding" and "high demanding" flights. In view of the fact that the parameters studied in this experiment are strongly dependent on the time of day all night flights were taken together to a third group. The following blood constituents were measured: 11-Hydroxycorticosteroids (11-OHCS), Glucose (BG), Cholesterol (CH), Adenosinetriphosphate (ATP), and the activities of three cell enzymes (MDH, GOT, GTP). The particular circumstances of this field study made it impossible to take control values immediately before the flights. Therefore controls were evaluated from blood samples that were taken on two nonflight days.

RESULTS AND DISCUSSION

A summary of the results is listed in Table 1. Controls are given in absolute units, stress values have been calculated as percent deviation. From the figures it can be seen that flying the F-104 G caused significant changes of most blood parameters. Comparing the low and the high demanding flights it becomes obvious that their sensitivity to flight stress differs distinctly (see also Figure 1).

After low demanding flights there is almost no change in the concentration of the blood constituents except for Glucose which increased 28 % above the preflight value. The high demanding flights on the other side caused significant changes of corticosteroids, and of the enzyme activities of MDH and GPT. Surprisingly a response of blood Glucose did not occur. Finally, Cholesterol and GOT remained unchanged as after the low demanding flights. An unequivocal validation of the night flight results at present seems to be difficult since at that time of day the influence of the circadian rhythm is extraordinary high (see Figure 2). If all flights are taken together to one group by averaging the stress responses in general are less distinct.

The operational significances of flight stress responses are summarized in the upper part of Figure 3. For comparison reasons responses to standardized stresses are presented in the lower part of this Figure. The same blood analyses after 30 minutes of standardized physical exercise, 30 minutes of acceleration, and after a 30 minutes low pressure period were conducted in former investigations. On the basis of these experiments it can be concluded that the flight stress responses in this study were of a moderate level.

From the results of this flight study it can be concluded that the blood constituents differ in their workload sensitivity: 11-OHCS, GPT, and MDH proved to be the most sensitive, GOT, ATP, and CH the most insensitive parameters. Finally, BG does not seem to be an unequivocal variable to measure flight stress.

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		MDH	GOT	GPT	ATP	BG	11-OHCS	CH
Controls	$\bar{x}$	46,0	8,9	7,3	24,8	69,2	20,6	203,8
	± S.D.	7,9	2,5	2,1	3,2	9,9	8,6	31,4
	n = 17							
Low Demanding Flights	$\bar{x}$	106,3	100,9	98,7	97,5	127,9	100,3	98,8
	± S.D.	27,7	24,9	23,3	12,6	31,4	24,6	8,7
	n = 16							
	P	0,4	0,9	0,9	0,6	0,005	0,9	0,7
High Demanding Flights	$\bar{x}$	116,0	106,2	113,7	97,1	103,8	120,7	99,5
	± S.D.	26,1	33,5	20,3	15,7	14,3	26,0	14,2
	n = 14							
	P	0,05	0,6	0,05	0,6	0,4	0,025	0,9
Night Flights	$\bar{x}$	109,2	113,4	87,7	93,9	118,8	59,1	88,3
	± S.D.	20,1	28,5	24,9	12,6	26,8	11,0	12,3
	n = 6							
	P	0,4	0,3	0,4	0,3	0,2	0,005	
Total Flights	$\bar{x}$	110,5	104,9	102,5	96,6	117,0	99,6	95,5
	± S.D.	26,2	27,9	23,7	13,5	27,0	31,2	16,5
	n = 36							
	P	0,05	0,4	0,6	0,2	0,001	0,9	0,3

Table 1: Mean pre- and postflight values (Controls for MDH, GOT, GPT in mU/ml, for ATP, BG, CH in mg %, and for 11-OHCS in µg/100 ml. Stress values in percent of individual controls)

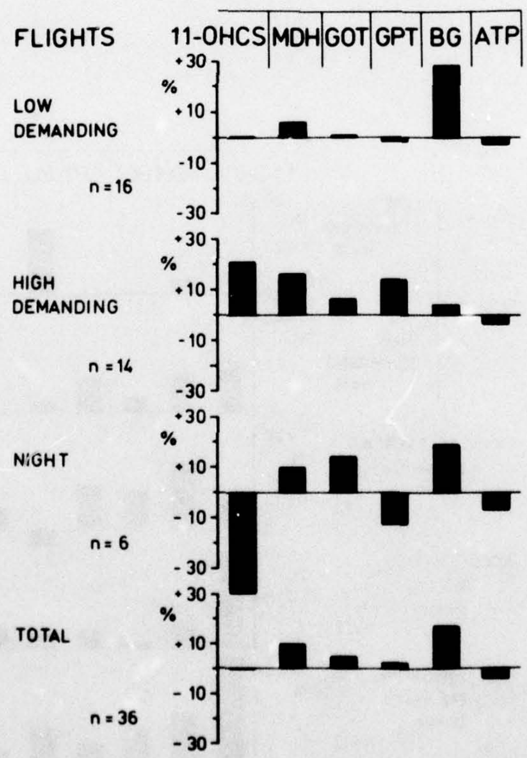

Figure 1 Responses of blood parameters to different flight missions. (Values in percent changes of controls)

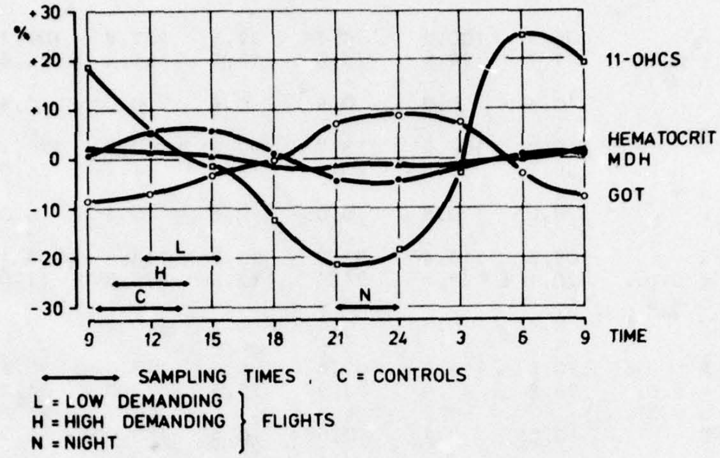

Figure 2 Variation of different blood constituents in dependency from time of day

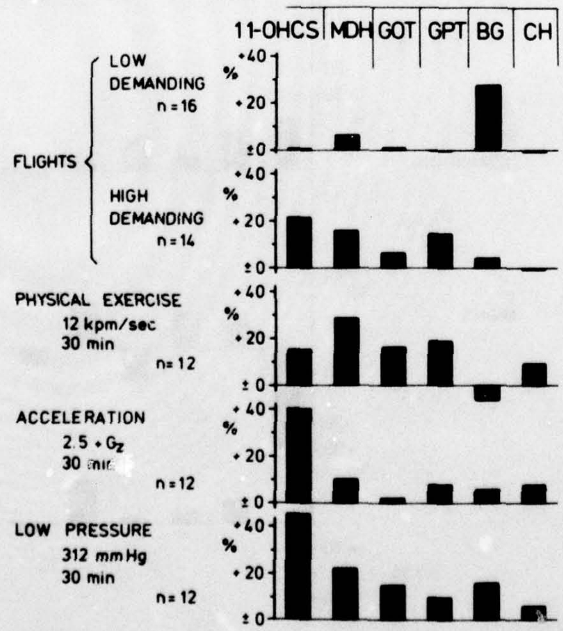

Figure 3 Comparison of responses to flights and standardized stressors.
(Values in percent changes of controls)

METHODS TO ASSESS PILOT WORKLOAD AND OTHER TEMPORAL INDICATORS OF PILOT PERFORMANCE EFFECTIVENESS

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SUMMARY

A systematic approach to define, measure and describe how certain pilot-related variables influence carrier landing performance during sustained operations is briefly outlined. Previous exploratory research on the interrelations between psychophysiological variables, pilot experience and performance is described. Pilot work activity, mood and sleep are identified as indicators of a pilot's temporal state of readiness. A field study design and techniques to measure and describe temporal readiness during prolonged flight operations are provided to demonstrate the methodology in an operational environment. Potential applications of the research are discussed along with the future role of temporal, psychological and other moderator variables in estimating pilot flight status.

INTRODUCTION

Preliminary interdisciplinary fleet studies of Navy pilot performance during prolonged periods of carrier flying have recently been completed (1, 2). Results of those studies indicate that changes in certain psychophysiological variables can be related to variations in pilot landing performance. A statistically significant multiple R of .84 ($n = 26$, $p < .01$) was obtained with four predictor variables which accounted for sixty-four percent of the performance criterion variance.

Aviation performance effectiveness was defined and standardized for the carrier operations by use of a previously validated Landing Performance Score (LPS) criterion. In the carrier studies three basic measures were used to describe the pilot environment. First, measures of pilot landing performance were recorded during a nine-month combat deployment off the Viet Nam coast. Second, physiological measures of stress as indicated by blood biochemistry were obtained during four time periods of the combat cruise to describe pilot reactions to variations in flight work load. A third category of pilot-related variables was that of sleep, pilot emotionality and pilot experience data. Pilot mood data were collected concurrent with biochemical data (four times); sleep data were obtained during one seven day cruise period; and pilot experience and biographical information were initially collected prior to the cruise to obtain baseline estimates of pilot background information. Those variables formed the basis of a measurement scheme designed to integrate performance, physiological, psychological, sleep and experience data into a comprehensive description of the influence of a combat environment on Navy fighter pilots.

The practical significance of the combat environment research lies in the systematic attempt to define, categorize and measure a host of interrelated variables that have been used in other research studies but which to our knowledge have not been combined and used to describe individual or collective stress effects for the same sample of pilots.

The research approach was exploratory in nature and represented a preliminary investigation of over 60 variables that were thought to be of potential interest in medically defining the combat environment for highly trained Navy pilots. From a host of variables we reduced the number to a more manageable and meaningful list in order to promote parsimony and a better grasp of the interrelations between stress, sleep, workload, mood, experience and pilot performance effectivenss.

Considerable time and analysis were given to the search for meaningful variables that could be used to reflect variations in pilot performance. A practical rather than purely theoretical method was used. Ultimately, we wanted to identify an easily applied technique that could be used by flight surgeons to determine reliably the flight status of pilots operating in stressful environments. Realistically, we know this was not accomplished easily or overnight. However, based on the first study, we are confident that combined and integrated sets of data collected on the same group of pilots during a carrier deployment will provide a better understanding, insight and identification of important variables that may prove useful to flight surgeons in estimating pilot readiness to perform operationally required missions in stressful environments.

The general conclusions of the preliminary study support the contention that integrated sets of pilot experience data, psychological test data and measures of a pilot's temporal state of readiness (sleep, mood, workload) can be related to pilot performance effectiveness. Collected concurrently with a valid and reliable criterion of pilot performance they appear to be a promising approach to understanding and predicting the influence of prolonged, stressful operations on pilot flight performance.

While the results provide significant statistical results, we now believe that refined data collection procedures and more stringent integration of the data which reflects a pilot's so-called temporal state of readiness with performance will result in measures more sensitive to pilot performance variation, especially in the night carrier landing environment. In retrospect, the first study did not provide

for concurrent and simultaneous data collection across mood, sleep and workload moderator variables. Those variables reflect a pilot's shifting, time oriented state of arousal to perform a particular task such as flying and landing a jet aircraft. By careful revision of the field data collection requirements and by incorporation of several additional predictor variables an efficient cross validation study can now be undertaken to verify and further explore the use of moderator variables as predictors of pilot fleet performance effectiveness.

This paper outlines a systematic method to carry out an operational study of pilot workload and other temporal indicators which influence pilot performance in a fleet environment.

MEASUREMENT AND PREDICTION OF COMBAT ENVIRONMENT PILOT PERFORMANCE

The results of the previous research were summarized in three separate reports (3, 4, 5) which were presented to a group of NATO-AGARD scientists who attended a conference on Simulation and Study of High Workload held in Oslo, Norway in April 1974.

Briefly, we found that pilot landing performance could be measured and collected longitudinally to describe variations in pilot effectiveness as a function of day and night operations. A method for comparing squadrons, air wings and individual pilots in terms of landing performance was established as feasible and operationally useful as an index of pilot performance. Landing Performance Scores(LPS) can be collected and analyzed to identify high and low proficiency pilots, potential night pilots, night performance decrement as a function of days since last landing, the effects of variable length line periods, and as a diagnostic feedback technique for improved pilot effectiveness. Perhaps the most practical application of the LPS is its use as a criterion to evaluate pilot proficiency.

To depict how temporal predictor variables interact during combat performance a simplified model was developed to account for the interrelations we encountered in the data. That model is shown in Figure 1.

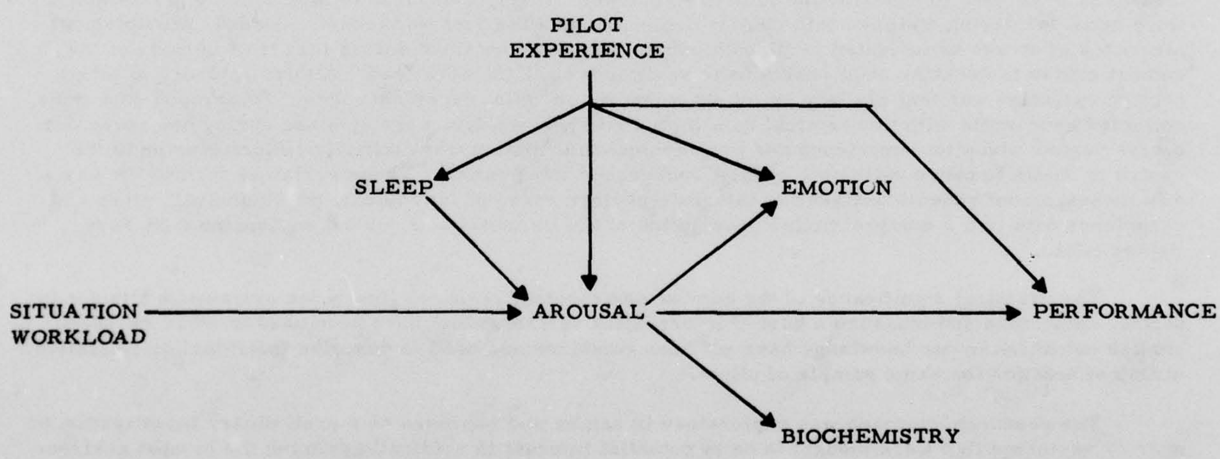

Figure 1. Pilot behavior arousal model predicting landing performance from measures of biochemistry, sleep, mood emotions and experience.

In our investigations we found that pilot landing performance could be predicted from a relatively small array of variables with various levels of success for different operationally defined pilot workloads. Five out of six multiple correlations were significant at the .05, or .01 level ranging from a high of $R = .84$, $n = 25$ ($p < .01$) to a low of $R = .63$ ($p < .05$) as shown in Figure 2. The variables were arranged in the model for descriptive and integrative rather than predictive purposes. In general, the most influential variable was pilot experience in the form of specific pilot flight hours in the F4J aircraft. Less important in the overall prediction of pilot landing performance were measures of mood. Feelings of depression and anger were found to be the only mood variables sensitive to pilot performance fluctuations.

The model serves to depict sequentially the interactive effects we obtained from our data analysis. We found that a combat situation results in a pilot arousal level that is influenced not only by sleep but also by a pilot's specific aircraft experience. Both variables intervene in a complex manner to affect a pilot's emotional level and blood biochemistry. Specific arousal levels were measured and described as a function of changes in sleep, workload and emotionality from baseline pilot data recorded during a nonstress period. This result is reminiscent of Helson's (6) theory of adaptation where changes in mood or affective levels would be reflected in behavior performance changes in a given combat situation. In addition, relative pilot experience appears to influence a pilot's initial capability to perform effectvely early in the cruise.

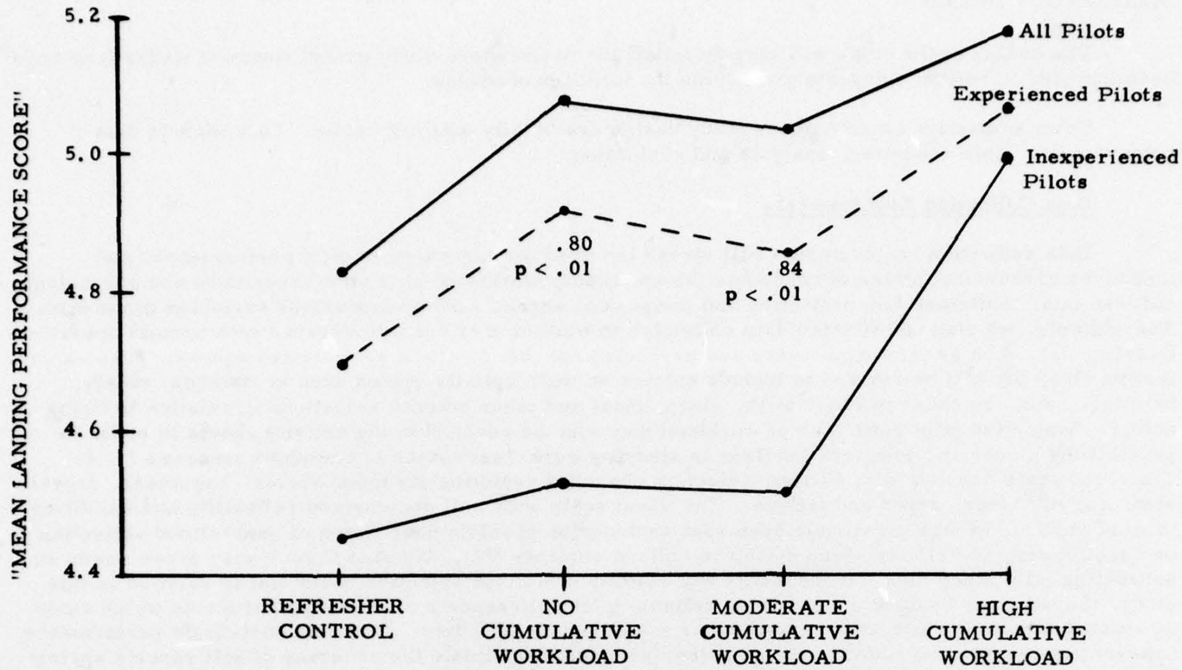

Figure 2. Summary of prediction of pilot landing performance from biochemical, mood and experience data.

At present, the model is suggestive of macroscopic interrelations between variables which can be utilized for data categorization in any future efforts.

In summary, pilot adaptation to stress which accumulates during prolonged flight operations appears to be facilitated by experience. As cumulative workload increases for experienced pilots they sustain a high level of performance while decreasing their cholesterol and feelings of depression. For inexperienced pilots as workload increases they improve their landing performance at a cost of continuing high levels of cholesterol and feelings of depression and fear. The increase in inexperienced pilot performance is obtained at a greater physiological and emotional cost than that reflected by identical measures for experienced pilots. For experienced pilots the adaptation to cumulative performance demands apparently results in a gradual decline in biochemical and emotional expenditure. It is as if pilots with experience adapt to stress and high workload while maintaining high performance. Inexperienced pilots, on the other hand, seem to require greater physiological and emotional energy to acquire the same performance as experienced aviators.

The study of naval aviators during prolonged combat operations indicates that pilots do not experience any total sleep loss compared to the crew. However, pilot sleep is more irregular and fragmented with sleep occurring on the average at 12 hour intervals compared with a crew average of 15 hours. Periods of wakefulness were 20 percent shorter for pilots than non-aviators. During the cruise the normal 16/8 wake-sleep cycle was disrupted for pilots who averaged only 12 hours between sleep cycles. As cumulative workload increased pilot sleep became more irregular, and the more irregular the sleep the lower the day landing performance for the pilots.

Of considerable interest to us was the realization that a large scale, interdisciplinary field study of a military population in an operational setting could be undertaken and successfully carried out. The research method outlined here uses information from the first study and presents a more comprehensive scheme with which to verify some of the initial results. Specifically:

1. *The data collection scheme is more systematic after a trial run.*
2. The potential relations we found between variables will facilitate analyses and evaluation of future data.
3. Liaison and field coordination efforts due to the first study would be greatly facilitated and are recognized as crucial to data collection success.
4. Cross-validation of the preliminary results would prove valuable to Navy medical teams interested in developing flight status prediction methods.

FIELD STUDY DESIGN

The design of the study *will closely follow the preliminary study except where modifications have* been included to refine, integrate and revise the initial procedures.

Other important aspects of the study design are briefly outlined below. They include data requirements, data reduction, analysis and evaluation.

Data Collection Requirements

Data collection requirements will stress the need for measures of pilot performance, and measures of temporal states of readiness (sleep, mood, workload) plus pilot experience and psychological test data. Efficient data collection and integration across various moderator variables is planned. For example, we plan coordinated data collection to minimize at sea interference with normal operations. Baseline data such as pilot experience and psychological test data will be collected ashore. Also, a subjective sleep log will be revised to include entries on work activity cycles such as watches, meals, briefings, etc., in order to chart work, sleep, meal and other activity variations in relation to flying duties. Subjective pilot *estimates of workload may also* be covered in the activity charts in order to parallel the pioneering work of Nicholson in studying work-rest cycles of transport aircrews (7, 8). The mood scale consists of a 40-item adjective checklist depicting six mood scales: happiness, depression, activity, fear, anger and fatique. The mood scale with well documented reliability and validities in field studies (9), has previously been used to describe physiological *states of generalized activation* or deactivation (10, 11) and sleep deficit in college students (12). We also think it may prove useful in estimating pilot sleep loss. If the utility and validity of a mood adjective check list is verified in this study, the way may be open for obtaining reliable pilot self-reports of physiological status which could be related to pilot performance variations as measured by *LPS* data. *Pre- and post-flight performance* assessment will also be added to the data requirements to estimate the accuracy of self reports against actual performance behavior. A preliminary study at NHRC indicates some relation between subjective assessment of performance and physiological arousal as measured by the mood adjective checklist.

Integration of the data requirements is designed to provide information on correlations between various moderator variables and performance as well as multiple correlation prediction of pilot performance. Potentially the mood adjective checklist may provide data sensitive to sleep, workload and performance variations and hence allow parsimony in future fleet data collection efforts. Out intention is to thoroughly test its operational potential in this study. An outline of the moderator and temporal predictor variables and performance data to be collected during the study is detailed in Table 1.

TABLE 1
DATA REQUIREMENTS

Sample: N = 50. F4 and A7 pilots
Representative groups of crew personnel for comparative data.

Shipboard Time: Minimum two weeks embarked - to collect night landing data

Criterion Measures

Landing Performance Score (LPS) Data (See Figure 3)

Minimum of twenty day and twenty night landings per pilot
LSO log books and scoring
Environmental data (weather, sea state, etc.)
Aircraft data: type and configuration
Carrier data: ship size, visual landing aids, accident rate, etc.
Boarding and bolter rate
Intervals between landings
Mission type and duration
Flying cycle work load estimate

Moderator/Predictor Variables

Temporal States of Readiness

Subjective Mood Data (See Figure 4)

Revised adjective mood checklist and scoring
Repeated measures pre- and post-flight
Baseline mood data in transit or ashore

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TABLE 1 (continued)

Moderator/Predictor Variables (continued)

Sleep and Workload Activity (See Figure 4)

Revised subjective sleep logs
Two weeks of sleep pattern data per pilot
Five days baseline sleep (non-flying shipboard)
Estimates of work - rest - meal - activity cycles

Pilot Experience Data

Age, height, weight, education
Aircraft experience
Instrument hours
Night hours
Number of day/night carrier landings
Accidents and incidents
Flight training grades and selection test data
RAG grades
Other Pensacola personnel data

Psychological Test Data

Rod and Frame
Group Embedded Figures
Hidden Figures
Perceptual Speed
Spatial Orientation
Spatial Visualization
Visual Pursuit
Others as specified

The procedure to be followed in data collection will stress collection of baseline mood, sleep and work-rest data during non-flying transit periods. It is expected that project personnel will be available to board the ship and collect the vast majority of data without unnecessary delays such as several short term visits to the ship. Arrangements will be made with local ship personnel to collect any straggler data, and also to provide local command contacts and liaison.

Data Reduction and Analysis

All moderator and performance data will be transformed to cards to facilitate computer reduction and analysis. The programming requirements will result in standard statistical descriptive data for all variables and provide a correlation matrix for use in analyzing results. Comparisons will be made between all sets of variables where appropriate, such as sleep versus mood, in order to estimate the relative influence and relationships between moderator variables. Primary importance will focus on cross validation of the multiple correlation obtained in the preliminary study. A new regression equation which uses sleep, mood and perceptual ability data as well as experience and workload variables to estimate pilot landing performance also will be developed, especially for night recovery. Considerable analysis time will be placed on obtaining factual evidence on the utility of the mood adjective checklist in estimating sleep loss, and ultimately any measure of association with actual landing performance.

RESULTS

It is expected that the results will include operational data to substantiate and develop further general hypotheses regarding the role of temporal, psychological and moderator variables in determining landing performance effectiveness. Descriptive and correlational data on pilot sleep patterns, and mood variations will also be provided. The study will report on the evaluation of various data collection instruments and their potential use in providing rapid, objective means for estimating changes in pilot performance. A system of scoring templates may also be developed in an attempt to describe moderator scoring formulae that will identify pilot sleep loss, mood change or other variations that are found to be related to changes in flight performance effectiveness.

If the results substantiate some of our preliminary hypotheses it may be possible to provide flight surgeons and operational commanders with more reliable methods to estimate pilot flight readiness during sustained carrier operations.

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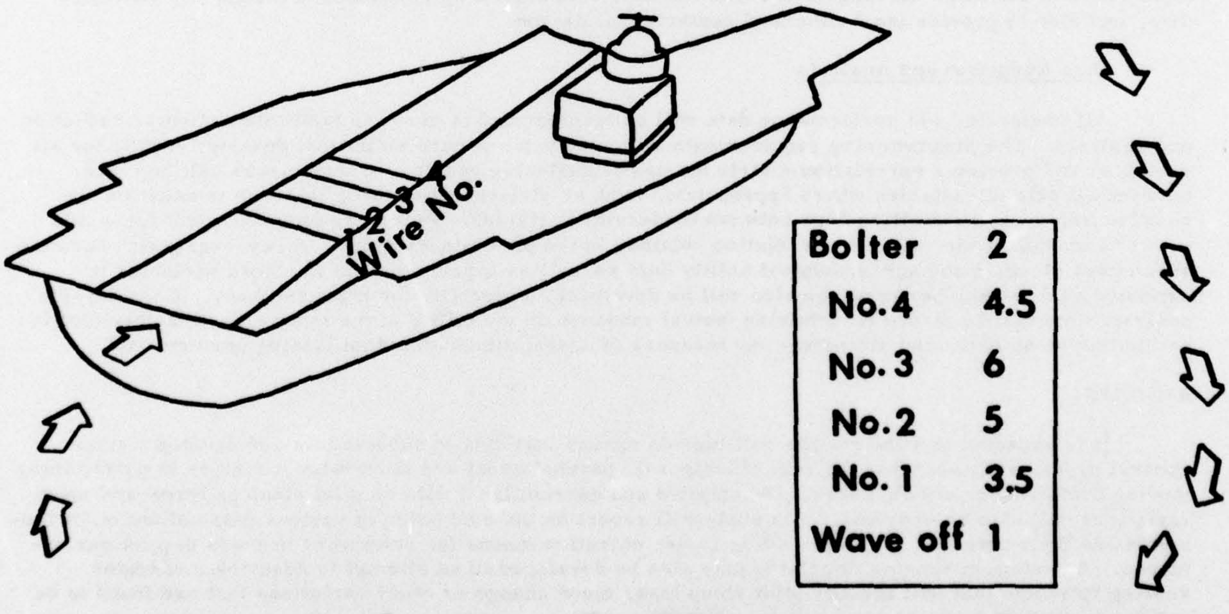

Bolter	2
No.4	4.5
No.3	6
No.2	5
No.1	3.5
Wave off	1

$$LPS_i \doteq b_1X_{1,i} + b_2X_{2,i} + \cdots + b_{k,i}X_{k,i}$$

Predicted Performance

Relative Importance of K Predictors

Figure 3. Derivation of Landing Performance Score

Figure 4. Example of pilot daily activity/mood sheet.

DAILY ACTIVITY/MOOD SHEET	NAME:	DATE:	TIME:

INSTRUCTIONS: Please fill out each morning for the previous day's activities. The daily activity chart below is broken into 1/2 hour time blocks. Place the proper numerical activity code in each of the blocks so that each 1/2 hour segment is covered by some activity. Please draw lines from start to stop of a code.

EXAMPLE: 2 — 2 1 — 1 2 4 — 4

DAILY ACTIVITY CODES

1. Flying (eng. start/stop)
2. Pre/Post Flight work
3. Squadron Work
4. Eating
5. Sleeping & Naps
6. Exercise
7. All Other Non-Work Activity.

DAYTIME

08 09 10 11 12 13 14 15 16 17 18 19

NIGHT TIME

20 21 22 23 24 01 02 03 04 05 06 07

How much trouble did you have going to sleep last night?

☐ none ☐ slight ☐ moderate ☐ considerable.

How many minutes did it take you to fall asleep last night? ____________.

How rested do you feel? ☐ well rested ☐ slightly rested ☐ moderately rested ☐ not at all rested

MOOD QUESTIONNAIRE

BELOW IS A LIST OF WORDS DESCRIBING MOODS AND FEELINGS. INDICATE HOW EACH WORK APPLIES TO HOW YOU FEEL **NOW** BY MAKING A HEAVY DARK MARK BETWEEN THE APPROPRIATE LINES USING THE SCALE LISTED BELOW:

1 = Not at all 2 = Somewhat *or* slightly 3 = Mostly *or* generally

	1 2 3		1 2 3		1 2 3		1 2 3
1. LOW	▯ ▯ ▯	11. CALM	▯ ▯ ▯	21. DOWNCAST	▯ ▯ ▯	31. ALERT	▯ ▯ ▯
2. LIVELY	▯ ▯ ▯	12. BLUE	▯ ▯ ▯	22. PLEASED	▯ ▯ ▯	32. ANNOYED	▯ ▯ ▯
3. IRRITATED	▯ ▯ ▯	13. BURNED UP	▯ ▯ ▯	23. SATISFIED	▯ ▯ ▯	33. SAD	▯ ▯ ▯
4. CONTENTED	▯ ▯ ▯	14. STEADY	▯ ▯ ▯	24. DEPRESSED	▯ ▯ ▯	34. HOPELESS	▯ ▯ ▯
5. ACTIVE	▯ ▯ ▯	15. AFRAID	▯ ▯ ▯	25. ENERGETIC	▯ ▯ ▯	35. INSECURE	▯ ▯ ▯
6. RESTFUL	▯ ▯ ▯	16. HAPPY	▯ ▯ ▯	26. CHEERFUL	▯ ▯ ▯	36. JITTERY	▯ ▯ ▯
7. IMPATIENT	▯ ▯ ▯	17. MISERABLE	▯ ▯ ▯	27. UNEASY	▯ ▯ ▯	37. BORED	▯ ▯ ▯
8. MEAN	▯ ▯ ▯	18. ALARMED	▯ ▯ ▯	28. GROUCHY	▯ ▯ ▯	38. TIRED	▯ ▯ ▯
9. WEARY	▯ ▯ ▯	19. LAZY	▯ ▯ ▯	29. SLUGGISH	▯ ▯ ▯	39. GOOD	▯ ▯ ▯
10. ANXIOUS	▯ ▯ ▯	20. DROWSY	▯ ▯ ▯	30. VIGOROUS	▯ ▯ ▯	40. ANGRY	▯ ▯ ▯

SUBJECTIVE RATINGS OF FLYING QUALITIES AND PILOT WORKLOAD IN THE OPERATION OF A SHORT HAUL JET TRANSPORT AIRCRAFT.

by

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SUMMARY

A representative sample of pilots employed by an airline operating a short haul jet transport aircraft assessed the acceptability of the cockpit layout and instrumentation, the handling quality, and the feasibility of the system operation in regard to the pilots workload. The assessment consisted of two parts: 1) a questionnaire of 82 fixed items being answered on a 7 step rating scale. 2) a semi-structured interview concerning 19 items, being answered on tape recorder. The justification to apply "subjective" ratings as a scientific method, instead of measuring objectively the physiological and psychological reactions of the pilot is to be seen in the output: Critical points and favourable capabilities of the man-machine-system can be evaluated economically and objectively, provided some premises are given.

Objective parameters like physiological and aircraft performance data have often failed as an independent indicator of pilot's work load and system quality. Moreover they are very expensive. In a critical review of the relevant literature it is demonstrated, that subjective assessment has turned out as a fairly valid and reliable mean for evaluating both man-machine-system and work load.

The premises are: Carefully chosen questionnaire and interview strategy, a well established rating scale, and a sufficient sample of persons for statistical evidence of the data.

The method allows to get direct impression and recognition of the particular kinds of strain and attention needed to operate the system.

INTRODUCTION

"If a measurement is made on a physical object with an instrument (nonhuman) of some sort, the measure is an objective one and the resulting data lie along a physical continuum. When an observer estimates a measure, it is a subjective judgment and the estimates lie along a psychological continuum" (19).

Aeronautical as well as other engineering sciences need the application of metric philosophies to measure the physical conditions of a given system to define and compare it quantitatively within the same dimensions with other systems. If the engineer is developing a man-machine-system, he would of course need to apply a quantitative description of the behavior, the functions, the judgments, and the opinions of the man in the loop in terms which are compatible even with those of the physical subsystems.

The requirements of such a description should therefore fullfil the scientific criteria of measuring dimensions common for both the technical and human areas likely to be measured objectively, being valid and reliable, and possibly being a linear, consistent invariant and proportional parameter. So the demands on the criteria of a subjectively assessed psychological continuum have become more and more a pure scientific interest of measurement theories instead of the interest of practicability and applicability of an assessment technique for several purposes of relevant judgments.

GENERAL OBJECTIONS AGAINST THE SUBJECTIVE ASSESSMENT TECHNIQUES.

There has always been some reservation against such a psychological continuum claiming to be a respectable means of measuring things equivalent to physical methods. McDONNELL (20) described as one of the most serious problems "the unknown quantitative character of rating scales". In fact the physically determined continuum in flight mechanics lacks in showing any definite criteria relating to the subjective feeling and rating of handling characteristics (10). One assesses the acceptability of a special system characteristic but not the characteristic itself. And "unfortunately, the current connections between pilot ratings, pilot behavior, and vehicle characteristics are, at best highly qualitative" (19). And furthermore some investigators argue that pilot ratings about the system qualities would reflect the rating decision process itself during his evaluation and more or less the personal traits or the attitudes toward the rated system instead of the "real" system quality. And a more general prejudice against any subjective assessment says that the result of questioning men would only be opinions about the system but not a direct indication of the system's impact itself (34).

The broad range of inter- and intraindividual differences and tolerances in the wide fields of human activities, behaviors and feelings may cause a great uncertainty about the human capability to work as a perfect measuring system. And it is evident that individual system operators like pilots, ATC-Controllers and others vary widely in their levels of training, experience, emotional stability, state of attention, technical comprehension of the system functions and information processing of data displayed and response dynamics of the system.

Perhaps there is something like a halo-effect against the real value of the pilot's subjective assessment particularly with respect to a remaining uncertainty concerning the overall likelihood of man to be influenced or manipulated by several intrinsic or extrinsic effects. Some persons can not have an unbiased look at the opinions of others because they, as self-designated experts, regard their own judgment as the only correct one. "Unfortunately, there are not two pilots who can agree when cockpit layout is discussed. Therefore, the designer must be a master in compromise since his efforts are judged by pilot representatives before the airplane is ever built. Therefore, the basic design must be flexible enough to allow compromise and change at minimal cost from customer to customer" (38).

This statement, made by a representative of the aviation industry certainly points out the urgency for improving the operator's assessing methods and for applying them already within the earliest phases of designing and producing a new equipment.

One of the reasons for the often stated inter- and intraindividual inconsistency of the pilot's opinions on the handling qualities of many aircraft systems is the wrong and unvalidated assumption that the rating scale is an equal interval scale and therefore the sharp inflexions of the ratings would represent the parameter of the system alteration. On the contrary by using the rankings of aircraft handling rating scales, CORKINDALE (7) and MURRELL (23) could experimentally demonstrate "that the items did not appear to be used as an equal interval scale, nor were the items used in the order in which they are presented in the scale" (26).

Another point of reservation against subjective methods is the insufficient definition of the outside conditions in investigation. In fact it seems to be almost impossible to maintain stable surrounding conditions of a couple of flight missions.

Nearly the same objections exist against the subjective judging methods in the field of subjective assessing the different sensations of dynamic stimuli, levels of comfort, fatigue, strain, risk, work load, and other individual states of feeling; they are basically unreliable because of the widely different correlations between the individuals, situations, demanding conditions, and because of their high proportion of indefinite variances.

THE CRITICAL VIEW AT OBJECTIVITY AS A MEASUREMENT CRITERIUM.

Since instrumental measurement of a physical parameter is the only objective method, from the engineering point of view it seems to be worth quoting the general definition of objectivity given by FLANAGAN (8): "By objectivity is meant the tendency for a number of independent observers to make the same report", or with a short term by GUILFORD (11): "Objectivity means interpersonal agreement", and more generally by TRAXEL (37) as the controllability of the intersubjective agreement by determining the concordance coefficient as a numeric equivalent of a gradually marked continuum. So it is evident that the existence of a physical continuum measured by calibrated instruments may not be the main or the only conditions for an objective measurement. And furthermore, a measure does not become objective only because it is quantitatively determined.

In the fields of socalled objective measurements seem to be too many expectations toward the reliability and validity of the collected data with respect to a certain criterion. The objective measurement itself does not necessarily guarantee reliability or validity of the data sample (27, 32). HOWITT (15) reminds "that although the measurements themselves may be very precise, their meaning (in terms of relevance or the total task or the cost to the pilot) may not be precise nor even very clear."

For measuring the physiological indications corresponding with the different states of pilot's activities, mental efforts, and levels of neurovegetative arousal there has been done a lot of useful work up to today, though with different results. The main reasons for the doubtful success of the physiological measures of workload are the difficulties of coping with the changing conditions in the field studies and of proving that they really indicate a change in task load or performance. Most of the particular physiological methods of measuring work load lack in consistency and reliability of the concerned parameter. They vary widely because of uncontrollable effects from situation to situation, from task to task and within the same task from time to time (4, 6, 30, 36).

HOWITT concluded in his investigations concerning the immediate work load, "there is now evidence to suggest that before long it will be possible to use physiological measurements to assess the pilot's level of arousal in terms of those which are optimal for the particular flying task". But concerning the duty-day work load he added "we do not as yet have anything better to use than the pilot's subjective opinion" (14).

"What is lacking at present, is a measure of change of performance that can be shown to correspond with these measured changes in indications of arousal level". "We are left therefore with our best physiological measure, heart rate, as no more and no less than a useful tool for estimating change of arousal level under different circumstances. It can be used as a comparison but not as an absolute measure of workload" (15).

THE LIMITATIONS OF OBJECTIVELY MEASURING METHODS.

The application of the known physiological measures under realistic conditions during a flight mission is limited by reasons of practicability and should therefore meet the following requirements:

- The hypothesis for the application of a certain method should widely be verified by scientific experimental studies so that a successful approach in the particular field investigation may reasonably be expected.
- The application of several physiological measurement techniques usually requires a high expenditure of weight, space, special engineering arrangements and unhandiness aboard aircrafts and therefore needs a careful and limited choice of the suitable apparatus.
- Physiological measurement methods offer the successful approach within a workload study only if all the crucial conditions and essential effects of the flight mission in investigation may be controlled like test variables.
- Some physiological measurement techniques may not be taken for granted to be agreed upon by the pilots involved. They may induce uncontrollable influences and have to be selected with respect to the acceptability by the pilots and to the possibility of interferences with the primary task.

Considering such limiting requirements of practicability only few of the numerous physiological measurement techniques are suitable to be applied during a routine mission flight. All physiological measures concerning the workload or the efforts or strain of a task may only be interpreted if they are simultaneously applied with other measures backing up the criterion in question. The complexity of data recording and interpretation and the response time of some physiological measure relative to task demands need additional expensive techniques and qualifications (9).

On the other side the time budget as another objective measure of the task load, or the objective measure of work result, the change of performance, or of the rate of failure may not alone and per se indicate the perceived strain and needed efforts during the work (6, 33).

"The central limitation here appears to be sensitivity, that is, task performance measure do not readily distinguish operationally meaningful differences in the effort associated with variations in task demand" (9).

JUSTIFICATION OF SUBJECTIVE ASSESSMENT TECHNIQUES.

It is the intention for this paper to reduce the above mentioned reservations against the subjective judgement as a measure to a rational minimum residue. One can get some relief on that by several investigators who published their experiences concerning the assessment techniques (3, 4, 6,9,18,20,21,24,29,30,33).

The revue of the recent literature on this field shows an increasing scepticism against the possibility and efficiency of objectively measuring the work load. At the same time the investigators more and more recourse to the subjectively judging techniques and this trend is obviously going on.

"In industry and everyday life it is often necessary to measure some variable although there is no technology for doing so, and human judgement is used instead" (1). The subjective judgement relative to an experienced average is used for measures where no objective and direct measuring technique is available whether concerning to estimate an object or to assess the state of the own feeling or to judge other people (22). These "judgement is a process of categorisation with reference to the average and range of values expected. Adaptation to a particular context can allow quite fine distinctions between these categories" (1).

Man has the aptitude to judge an object along a certain continuum like a quasi statistician if one gives him the opportunity to acquire a certain amount of experience to observe a certain spectrum of that continuum.

SINCLAIR (32) describes "three occasions on which the use of subjective judgement is important; first when the data cannot be obtained easily by other methods, secondly for corroboration of data obtained by other means, and thirdly when the subject's attitudes, or strategies of action, are likely to affect some aspects of observed behaviour in the problem situation". And BRIGHAM (2) stated, "that subjects can make judgements involving the simultaneous assessment of several attitudes of the stimulus in question".

The subjective techniques "are often the best method for measuring workload in the operational environment" (33).

And HOWITT (15) stated: "The opinion of a well motivated crew member is very valuable provided the right questions have been put to him and put in a proper manner ... It is he whose workload is in question and he who is experiencing and has intimate knowledge of the variables that go up to make that workload. Recently the subjective score has come into favour again although mainly as a back-up to objective measurements. In fact most of the objective measures rely ultimately on a subjective assessment to put them on to some sort of scale meaningful in the real world situation".

"Pilot evaluation still remains the only method of assessing the interactions between pilot-vehicle performance and total workload in determining suitability of an airplane for the mission" (6). And finally these subjective measure has in fact always been "the ultimate criterion against which the success or failure of a control system design has been evaluated" (17).

The direct participation of the pilots in the system evaluation corresponds to their function as autonomous, responsible, and competent crewmembers whc live with their systems and whose professional existence, capacity, and satisfaction are very closely linked with their operational system.

SOME ADVANTAGES OF SUBJECTIVE ASSESSMENT TECHNIQUES.

There is no question about the advantages of the application of subjective method either as questionnaire, as rating scale, as checklist, as profile rating, or as a qualitative comment.

The actual distributions of ratings of some system characteristics often show a shape similar to the binomial distribution (10). Especially the rating scales have a remarkable effectivity within the range of normal conditions in the hands of a skilled observer. Of course there are no absolute measuring units which are calibrated on the continuum itself, and it can not be expected that an exact metric will exist for each case on the level of either intervall scales or relative or absolute scales. It also does not seem possible in the near future to define the grade of a work load in the sense of a factor of a certain reference load.

But on the other side several authors have found high correlations between limited dimensions of demands and the subjective rating, e. g. between the physical effort and fatigue and pilot rating (6, 16, 18).

Furthermore HESS's study (13) indicated "that a human can transpose his impressing of a task directly to a linear numerical index. The lack of adjectives does not appear to detract from his ability to generate subjective opinion". And of course approximations are possible in the sense of practicability so that it is at least possible to identify the main sources of a work load, to determine undoubtedly some overloads for a defined sample of persons within a certain degree of significance (12).

The pilot's judgement is capable to cover with one connotation a lot of influences at the same time which may vary the demands. On the other hand a device of measuring any performance is not able to cover in combination and adequately weighted some more variables together within a single scale. The human perception possesses an enormous capacity of information processing and it functions with a high selection rate and flexibility of coping with unforeseen and complex situations as well as with simply and fixedly conditioned processes whilst the pilot is assessing and judging a certain object.

The man in his role as a pilot of high performance aircraft is "capable of attaining essentially the same performance for a wide range of vehicle characteristics, at the expense of significant reductions in his capacity to assume other duties and to plan subsequent operations" (6).

So the pilot with this capability as an adaptive controller is also able to extrapolate a judgement from one phase condition to another phase with varying conditions and demands. His judging works considering both performance configurations of the system and his own effort and attention to cope with the task demands. A flight phase rating largely bases on the pilot's ability to draw on his knowledge, previous experience, and on the use of pilot-induced disturbancies or selfinduced tasks (6). (Table 1)

CRITERIA FOR THE APPLICATION OF SUBJECTIVE ASSESSMENT TECHNIQUES.

A critical review of the relevant literature may demonstrate that subjective assessment techniques have turned out to be a fairly valid and reliable means for evaluating both the handling and information processing characteristics of man-machine-systems, and the work load and efforts or strain of the men within the loop. The application of assessing methods starts from the hypothesis that a certain relation exists between the subjective judgement on the one hand and the real behavior of the operator during the particular work in the system, the real behavior of the system at all, and the handling qualities on the system on the other hand. But in order to guarantee that the methods applied really work as adopted they have to comply with some important criteria which are the essentials for the achievement of assessment objectives. They are summarized as followed (Table 2):

(1) <u>Clarity of focus (9).</u>

That is the unbiased semantic meaning of the verbal questioning which "serve to clearly distinguish the phenomena of interest ... It does require that clear distinctions be made among the alternative concept referents ... (e.g., task demands, effort, feelings, energy levels) and between these phenomena and such related phenomena as conditions in the task environment, situational stressors, personality variables, or the wide range of acute and chronic effects attributed to workload or fatigue" (9).

(2) Operational relevance (9).

This criterion means that the experimental tasks are approximately compatible with the level of complexity of the demands placed on the human operator as a part of the machine-system (5). "And this requires both the identification of actual task demands and the specification of functional relationships between these demands and the concepts, indicators, measures, and procedures employed in the research setting" (9). This criterion is similar to that of validity which "has to do with the degree to which what is measured represents the true situation" (31).

(3) Practical significance (9).

The relevant assessment techniques should "be sensitive to operationally meaningful differences in independent variables" and "consider the actual impact of measured levels of workload or fatigue on the quality of system performance and on the psychological and physiological well-being of individuals affected by system operations" (9). That is nearly the same criterion which is termed as "Ease of interpretability" "providing information in a form which allows anwers to be obtained in relation to the problem under investigation" (30).

(4) Freedom of interference (9, 30).

"The measurement technique must not interfere with ongoing primary task performance" (9). That is mostly the case "if used simultaneously with the task under performance" (30).

(5) Pilot acceptance

"The technique should not expose the subject to any discomfort or cause any apprehension" (30) or "negative pilot acceptance attitude" (9).

(6) Reliability and consistency of the measurement

"Any variability which should occur in the measure would be due to variations in the task or operator rather than to the measure itself" (30).

Reliability is concerned with internal consistency so "that comparable questions regarding the same topic should yield equivalent answers" (18, 25, 32).

A sufficiently high reliability may be expected if the before mentioned criteria are considered. Besides these the reliability depends on the kind of rating scale or answering form to be used, the definition of anchoring and intervals within the concerned continuum. It has additionally to be payed attention to the homogenous sample of subjects and to the proper preparation of all the persons who are involved in the questioning procedures by previous discussions and definition of the aids and aims. They have to be trained or briefed in the careful application of the concepts set out for the particular assessment. (Table 2)

PILOT OPINION SURVEY CONDUCTED ON A SHORT HAUL FLIGHT OPERATION. DESCRIPTION OF THE METHOD.

It is not so much the purely scientific interest at first to give the subjective assessment a methodological justification. But there is a primary interest to make sure that a sufficiently reliable and valid judgement instrument may be available for the very practical purposes of checking the acceptability of system characteristics and the workload under the real operational conditions. And here there is no doubt that under real life conditions questioning techniques are easier to handle, more economically to apply, more direct to interprete, and they admit a more direct and copious evidence to the matter in question.

So we have conducted a socalled pilot study (35) in order to prove in principle that this hypothesis may be confirmed. The YAK 40-aircraft operation was used as an example to develop the opinion survey study. A questionnaire was used to assess the quality of the entire aircraft control system, including the features of the work space, the equipment, the system and handling qualities, and the workload while operating that system, the set of questions taking due account of the ten workload factors as described in Appendix D of the certification of airworthiness (FAR, Part 25).

The questions regarding the aircraft YAK 40 include 65 items that relate to specific components of the system itself. The pilots completing the questionnaire were asked to assess the quality of each particular component by placing a cross in one of seven boxes that range from "very good" to "very poor" to be accepted under the experienced conditions, and to do this at first without adding any comments. Such description of the system may also give reasons for the next series of ratings. (Table 3)

The items 66-70 include questions which relate to the special attitude of the pilots to the operation on this type of aircraft and to the subjectively perceived stress and workload whilst flying it.

As fas as the series of question 71 to 82 are concerned, the same rating procedure is to be used to estimate to what extent the performance of this piloting system can be adversely affected by external disturbances, environmental influences and system disorders.

The next nineteen questions (83 to 101) are so-called open questions, the pilots being requested to give a detailed oral account of their experiences with the system in operation and some additional comments to their workload judgement. The greater part of these questions once again relates to the system components listed in questions 1 - 65 and 71 - 82. The quantitative assessment of these components now finds its counterpart in a qualitative description of their critical qualities. The quantitative form of judgement can be statistically evaluated and thus constitute a sort of control against the may be one-sidedly subjective opinions and a regulator of typical judgement errors.

The weighting of the assessments in relation to the overall system is enabled by the statistical evaluation of the scaled ratings. Moreover, the descriptions and ratings of the critical elements include a wealth of day-to-day flying experience which could not be obtained from a limited member of test flights.

The answers to the open questions are followed by a short discussion in order to elucidate the intended meaning and the valuable background information. In spite of the difficulty of their quantitative evaluation "the informal chat as an unstructured interview can be very profitable and it is probably the best way of bearing all the subject's pet grouses" (31).

SOME RESULTS OF THE COCKPIT-STUDY BY RATINGS AND QUESTIONNING.

The average rating on the seven points scale is 4,00 and may be described as representing an adequate system quality. Those system qualities that were clearly assessed byboth groups with a positive value (M = 3,00 or less) include control of the electrical trim (item 17), look out on taxiing (item 23), behavior of aircraft in slow flight (item 42), recovery behavior of aircraft after STALL-clean (item 43), recovery after STALL-landing configuration (item 44), normal go around (item 45), touch-down speed (item 48), monitoring engine gauges (item 50), abnormal procedure on hydraulic system failure (item 54). So most of the essential flying qualities of the aircraft were rated as rather good-natured.

On the other hand the 9 random selected captains who answered the questionnaire rated 29 items below average, the 9 involved copilots rated 23 items below average. Both groups rated the following qualities with a mean of more than 5,00 which are representing very badly acceptible properties of the system: control wheel (item 5), flaps setting (item 19), windshield wipers equipment (item 24), cabin pressurization (item 51). And the pilots in command added some more extremly bad values namly: comfort of the seat (item 4), lighting of instruments (item 10), control forces on aileron (item 34), reverse handling and effects (item 49), handling of the electric systems (item 53), storage space for crew's equipment and baggage (item 65). These very negative ratings represent more the handling qualities of the systems and reflect a severe impact on the acceptability of the aircraft at all due to the lot of severe deficiencies.

When one bears in mind the numerous system elements that had been very critically assessed, the pilots show an amazingly carefree and unworried reaction to the question 67 concerning the work load perceived during the last few flights, and to question 68 concerning the level of confidence (versus apprehension) outlooking the next trip. Only the copilots rated the workload slightly below average but with a relative high uncertainty (s = 2,09). Similar results were found for the risk pressure deriving from the possibility of having to cope with failures and their consequences (question 69). Here the copilots feel even less constraint than the pilots in command. But both they rated a low psychic stress from risk pressure.

The only item which may reflect some stress due to the above mentioned system deficiencies is question 70 concerning the assessment of the pressure of responsibility for the safety of other people and for completing the mission as planned. The responsibility level in mind is a little higher than average and the copilots assessed the degree of responsibility to be greater than their more experienced collegues on the left seat had in mind. They all did not fear the risks or danger of failure but only the stress of responsibility having to operate on an aircraft with so many substantial complaints about the low level of human engineered cockpit concept.

Some of these complaints are described above by ratings of the particular elements, some are reflected on the questions 71 to 82 about the most disturbing factors which can reduce the performance of this aircraft control system. There are three factors which are rated below average and are described as disturbing the normal operation, namely the temperature control (item 75), the traffic density (item 77) and the pressurization control (item 82). But it is noticable that only the copilots rated that factors as disturbing influences because they typically concern their own part of work. These ratings appear like a reinforcement of the judgements of the badly acceptable elements. The workload especially of the copilots is growing up with the time pressure to cope simultaneously with the different complicated system management and with the increasing density of the traffic.

This higher level of work load and responsibility stress has been found reflected on the more detailed and qualitative descriptions of the pilot's experience within the operation of the aircraft on hands of the open questions. The detailed comments given to these questions and during the following interviews contain a lot of arguments which may substantiate the quantitave ratings and give reasons for in more detailed explanations.

The reliability of such statements may be calculated by destining quantitatively the level of concordance on content and frequency of a certain item description. But this would be a pretty expensive job.

The evaluation of these open questions confirmed that, notwithstanding the lowish risk stress and higher confidence level during the flights, all the pilots were very conscious of the responsibility that derives from the several deficiencies of this aircraft design. This higher responsibility stress is particularely the result of temporary peak demands made on the pilots in turbulent weather due to the high load on control wheel forces, the difficulties in operating the systems of the aircraft in high traffic density conditions due to the time pressure conflicting with the sophisticated demands on the systems handling especially for the copilot, and as far as the pilot in command is concerned, the need for supervising the activities of his copilot under such severe conditions.

All these facts of loading conditions call for a higher degree of watchful supervision of the entire course of events. This higher level of attention enable the pilots, notwithstanding the numerous deficiencies, to operate the aircraft without a sense of danger, risk, a loss of confidence, or a significant perceived stress. It also provides the explanation why, when all is said and done and on account of the greater demands made on the pilot's attention, this aircraft nevertheless appears to be acceptable in the view of the pilots. They handled the routine operation of the aircraft with no more than average rate of technical failure and delay as similar to other line operations. But one accident happened yet after completing the survey just due to one of the worst rated component of the system, namely the reverse handling of the central engine. The aircraft had overshooted the runway and was destroyed because of the improper handling of the reverse system. But this system shows some typical deficiencies which are in several senses in contrary to the basic principles of human engineering.

CONCLUSION.

Surveying the relevant literature it is emphasized that the subjective assessment techniques have become instruments of increasing value in the wide fields of their application. Such techniques lead to rather reliable and valid statements about the flying qualities of the aircraft, the handling qualities of the systems, the quality of the cockpit layout, as well as of the workload induced on and the stress received by the crew, always provided that subjective judging errors can be reduced and kept within normal limits by means of a carefully selected and systematic questioning strategy. However, the following requirements have to be met:

1. The survey must cover an adequately representative sample of pilots.
2. The state of training and experience of the pilots must be taken into consideration as an independent variable that exerts a relevant influence on the way the questions are answered.
3. The questions must be carefully formulated and their contents must be unambiguously concerned with an accurately defined element of the system or particular criterion to be judged.
4. The set of questions should be as complete as possible, i. e. it must cover not only all the individual elements of the system, but also as far as possible the dynamic components that occur during the real operation of the aircraft.
5. The set of questions should include a multiple approach in order to cover more than one view of the problem investigated. That means the application of some different kinds of questioning techniques on the same project, i.e. rating techniques, questionnaires, checklists, open comments on prepared questions, and last not least the open interview.

We have tried to apply exemplaryly such techniques on a certain type of aircraft in order to check the level of acceptability of the induced stress, and work load during the operation on that system.

To my opinion it is not only possible to apply such techniques with respectible results but also to furtherly develop these techniques to even more sophisticated and more reliable and valid instruments. We should emphasize to do this in the near future more consequently.

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Table 1: **THE ADVANTAGES OF THE APPLICATION OF SUBJECTIVE ASSESSMENT TECHNIQUES**

1. EASINESS OF HANDLING
2. DIRECT INTERPRETATION
3. RANGE OF FACTUAL RELEVANCE
4. INDEPENDENCE OF TEST CONDITIONS
5. LOW ECONOMICAL EXPENDITURE
6. SUFFICIENT RELIABILITY

Table 2: **THE MOST IMPORTANT CRITERIA FOR THE APPLICATION OF SUBJECTIVE ASSESSMENT TECHNIQUES**

1. CLARITY OF FOCUS
2. OPERATIONAL RELEVANCE
3. PRACTICAL SIGNIFICANCE
4. FREEDOM OF INTERFERENCE
5. PILOT ACCEPTANCE
6. RELIABLE MEASUREMENT

Table 3: Mean Values and Standard Deviations of the Rating Scales

Item No.	System Elements	M	Commanders 1 2 3 4 5 6 7	s	M	Copilots 1 2 3 4 5 6 7	s
4	Seat comfort	6,11		1,05	4,56		1,24
5	Control column/wheel	5,56		1,13	6,00		1,12
10	Instrument lighting	5,00		1,11	4,33		1,12
17	Electrical trim control	2,89		1,05	2,78		1,99
19	Flaps setting	6,00		1,00	5,89		1,27
23	Look out on taxiing	2,33		0,86	2,22		0,67
24	Windshield wipers	5,33		1,41	5,22		1,09
26	Nosewheel steering	4,44		1,58	4,33		1,50
33	Control forces/Elevator	4,33		1,22	4,33		1,50
34	Control forces/Aileron	5,00		1,41	4,67		1,32
36	Control sensitivity	4,67		1,50	4,11		1,17
37	Roll rate	4,22		1,39	4,89		1,69
42	Slow flight	2,89		1,26	2,56		1,01
43	Recovery from stall clean	2,56		1,13	2,22		0,67
44	Recovery fr. stall landing config.	2,67		1,22	2,56		1,01
45	Normal go around	3,00		1,22	2,78		1,30
48	Touchdown speed	2,67		1,00	2,00		0,87
49	Reverse handling	5,22		0,97	4,67		1,87
50	Monitoring engine gauges	2,89		1,26	2,56		1,33
51	Cabin pressurization	5,89		0,78	6,00		1,22
53	Handling electrical systems	5,22		1,39	4,67		1,58
54	Handling hydraulic sytem failure	2,78		0,97	3,00		1,00
59	Loading procedures	4,78		1,64	5,33		1,32
64	Space for charts and flight log	4,78		1,48	4,56		1,42
65	Storage space	5,11		0,78	4,89		1,17
	Perceived Workload						
67	Workload during the last few flights (1=great)	4,11		1,45	3,89		2,09
68	Confidence level before starting your flights (1=great)	3,56		1,33	2,63		1,19
69	Level of risk pressure coping with techn.failure or error (1=high)	4,67		1,87	5,44		1,67
70	Responsibility pressure carrying out your missions (1=high)	3,89		1,76	2,89		2,09
	Impact on System Performance by Disturbing Factors						
75	Temperature control	3,78		1,30	4,44		1,67
77	Traffic density in congested areas	3,50		1,41	4,38		2,00
82	Trouble of pressurization	4,00		1,50	4,89		1,45
	Examples of the 19 Open Questions						
83	Which of the arrangements in the cockpit do you find to be disturbing?						
84	Which operating elements could lead to wrong handling, and why?						
85	Is the arrangement of the system elements optimal for all handling sequences?						
90	Which display systems can lead to inaccurate or erroneous interpretations?						
94	Which flying characteristic of this type of aircraft call for your special attention?						
95	Do you find the handling and operation of the existing autopilot to be satisfactorily designed?						
96	Is the degree of automation in the systems an adequate help for safe piloting?						
101	Are there any changes in your flying training that you deem absolutely necessary?						

DISCUSSION

M.G.Sanders: You mentioned that with subjective ratings you can measure on an interval scale. Hence, I wonder why you calculated means and standard deviations, which are in fact meaningless figures. Why did not you calculate medians and inter-quartile ranges which are meant as measures of central tendencies for data like yours?

K.Steininger: It is in fact one of the most difficult problems of subjective ratings to measure them on an interval scale. We did not stress this requirement of rating technique for the purpose of our investigation. The calculation of means and standard deviations was made in the first approach to evaluate the data, and I agree that the calculation of medians and inter-quartile ranges could give a more precise picture of the data central tendency. Of course, we will do so in the next stage of a following series of such cockpit studies in our project.

Subjective Stress Assessment as a Criterion for Measuring the Psychophysical Workload on Pilots

by

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Some years ago the German Air Force Institute of Aviation Medicine was ordered by the Federal Minister of Defence to search into the psychophysical workload on pilots operating military aircraft within the Federal Armed Forces.
This directive was based on the assumption, that flying pay should not be granted without a scientific basis for the justification of the differences between pilots of jet-, prop-, and helicopter aircraft.
First the term "psychophysical workload" must be clarified. It comprises the effects of the grand total workload on the human organism, human behaviour, and subjective feeling. GERBERT (1976) has defined this term in detail: "Psychophysical workload induced by an activity will not only depend upon duration and intensity of stressing stimuli, but also upon intra-individual factors in the stressed subject himself (physical features, functioning of the sensory organs, vegetative status, and present state of health as a prerequisite to physical performance; job-related knowledge, abilities, skills, need for achievement, experience, and emotional stress resistance as psychic and mental determinants of strain)!" In consensus with ROHMERT he states the following formula:

$$\begin{aligned}\text{workload} \;=\;& \text{expenditure of somatic energy} \\ &+ \text{difficulty of task} \\ &\times \text{duration of activity}\end{aligned}$$

$$\text{strain} \;=\; \text{workload effect on the individual}$$

Having clarified, <u>what</u> is to be assessed and evaluated, the question arises, <u>how</u> it is to be measured and in what way it is to be interpreted.

Methods for the investigation of psychophysical strain parameters

When viewing workload effects as such, immediate physiological reactions are predominantly measured as strain parameters (engagement, arousal).

a) physiological examination methods: heart rate, arrhythmia of heart rate, respiratory volume, blood pressure, body temperature, skin resistance, microvibration a.s.o.
b) electrophysical methods: electrocardiogram (ECG), electroencephalogram (EEG) and others.
c) biochemical methods: blood-, urine, and parotis- saliva-analyses with regard to workload specific changes, respiratory quotient and so on.
d) methods of sensory psychology: they are based on the assumption, that perception thresholds will change under psychical and physical strain/fatigue. Main procedures: determination of critical flicker fusion (CFF).

For some time the Institute of Aviation Medicine attempted to cope with the task presented by using the above mentioned measurement methods.
When, however, it became evident, that the deadline set for an expert opinion on this problem would not permit the application of these methods, the physicians were faced with a thorny matter and they confronted the psychologists with the question, whether the measurement of psychic strain and workload might yield plausible results in time.

This in turn offered the following methodical possibilities:

e) work- and time studies by recording so-called actions and events (activities are recorded according to time sequence, frequence and duration).
f) evaluation of task difficulty by trained external experts.
   The following is evaluated:
   1. extent / diversity / apperception and output of information (the proportion of manual, mental and various cognitive processing work).
   2. Difficulty of task considering mental and emotional aspects.
g) application of secondary tasks: the information processing capacity remaining vacant while performing a task is filled "up to the brim" by additional tasks. The performance resp. performance fluctuation in the side task may - with certain reservation - be used as a measure for workload induced by the primary task.
h) registration of subjective assessments of workload situation through standardized interviews and questionnaires (acc. to GERBERT, 1976).

Of these psychological methods e) and g) were eliminated for reasons of time and f) because there were no trained external experts available.
Only method h) remained, namely the "registration of subjective assessments of workload situations" by means of standardized interviews and questionnaires.

How to get "subjective assessments"

From the foregoing it is evident, that methods to obtain subjective opinions can not be a substitute for objective scientific observations and experiments.

They are, however, a useful source of information and especially so in cases where scientific measuring is impossible for any reason whatever.
Such a judgement of experiences encountered is a piece of "phenomenal reality" (RADL, 1976). This is true even though one sometimes has the impression, that they are in contradiction to the verifiable results of objective procedures. This will have to be illustrated in detail later on. Among the most important methods of obtaining assessments are the following (acc. to RADL, 1976):

- free interview
- standardized interview
- qualitative questionnaire
- multiple choice questionnaire
- comparative judgements and
- graphic rating scale (polarity profile).

We decided to apply a combination of comparative judgements and graphic rating scales, making use of the advantages of both methods, namely:
- little expenditures for application and evaluation,
- comparison of intersubjective results were insured
- negligible falsification of results through the influence of the psychologist, interviewer or experimentalist,
- results are given in ordinal numbers.

A thorough scientific verification of the procedure for "subjective stress assessment" is to be found in publications by WEYER and HODAPP (1975): "...subjective indicators differ from the remaining "reaction methods" in that stress is not directly analysed. The subject is rather urged to be introspective. This is very well in agreement with scientific work. It is accomplished by asking the man more or less the direct questions concerning his subjective experience of strain or workload."

"Subjective Stress Assessment"

This term implies the following: instead of measuring well-defined parameters the examinee is asked a number of standardized questions. Standardized in this context means, that the possibilities to give answers are limited, predetermined and thus quantifiable. Every question concerns a stressor, which has been determined as being relevant. Simplified, a question goes like this:

"How does this stressor affect (strain) you?"

As an answer the examinee is required to enter a check mark on a scale with numbers ranging, for example, from zero to six.

High workload No workload
6 - 5 - 4 - 3 - 2 - 1 - 0

The instructions for filling in the scale are:
"On all scales looking like the above sample please mark the number which you think applies to you with a clear "X" on the line. The scale may be compared with a thermometer, whose one end is marked "hot" and the other end "cold". There is a gradual transition between both final points which you should consider as such, when we ask the questions. Wherever there are scales, there is no Either - Or !"
This method permits the computation of answers provided by examinees, e.g. the calculation of mean scores, variability scores and correlations.
Thus a subject can be given many more questions within the available time than would be possible during a less structured, not standardized interview, since the answer methodology is easily comprehensible and will permit many answers within a short period of time.
The disadvantage in comparison with an interview is, that one is not informed about the background, justification and the like, which might have led to the answer.
It is clear, that with such a scale we are not measuring workload as is done with meters or kilograms, but the scale can very well provide an answer how different groups of persons assess the same stressor as to its straining effect. To illustrate this, a simple example:
We address the following question to two groups of swimmers: "how high is the strain on you, if you are to swim one mile in one go?" Provided the first group consists of long-distance-swimmers and the second of short-distance swimming sprinters, the mean score of the first group is most likely in the vicinity of the score "2", whereas the second group will possibly score "5". You may put an additional question to the short-distance swimmers: "What do you think is the strain on long-distance swimmers over a distance of one mile?" and vice versa. If the groups know each other, the assessment of the other group will come close to the assessment by the own group. If this actually happens, two subjective assessments have resulted in one "quasi objective score"!
To complement the example of the swimmers: if you ask the short distance swimmers:"What do you think is the strain on long-distance swimmers over sprint-distance? and vice versa, the scores will be reversed. (Perhaps you know, that long-distance swimmers find it enormously difficult to sprint! and on the contrary sprinters are almost sure they would fail over long distances!)
If we add the workload in both disciplines for both groups, we will get similar total mean scores. Applied to aviation this example illustrates the importance of considering all stressors imaginable, when measuring workload - or in our case e s t i m a t i n g workload - , before arriving at conclusions about stress or strain.
A rough classification reveals the following major groups of stress factors in aviation

- environmental stressors,
- task stressors, and
- emotional stressors-

It is safe to assume, that physical workload is foremost the result of changes in environmental conditions inherent to flying (physical parameters, e.g. G-forces) = environmental stress.
Mental workload stems from the nearly continuous requirements on vigilance, perceptual-motor and intellectual activity in operating the aircraft and coping with navigation and mission-specific tasks = task stress.
Emotional strain is caused by the awareness of increased accident risk and responsibility = emotional stress. Depending upon the number of stress factors and the extent to which they act on the individual's body and psyche there are qualitatively and quantitatively different stress constellations for the various aircraft categories (jet, prop, and helo), aircraft types and missions.
To get a starting point in the investigation of these stress-constellations was one goal of our examinations with the questionnaire for "Subjective Stress Assessment" in addition to complying with the order given to us by the Ministry of Defence.
Now you may perhaps voice several objections, one being, that with questionnaires one would always have to reckon with f a k i n g . In a questionnaire concerning workload probably with exaggeration, in another one covering symptoms of anxiety probably with understatements and so on. First of all we readily admit these sources of errors, but we have done our best by assuring anonymity and by not clearly stating the purpose of questioning to obtain frank answers.
An indicator for the success of our efforts can be derived from the very low standard deviations of the scores in various groups and in most cases. Regarding the question for symptoms of f e a r o f f l y i n g our efforts have clearly failed. Probably certain psychic defence mechanisms prevailing in such socially not accepted spheres simply won't permit honest answers even when complete anonymity is assured. An observation, which KINSEY already had to make in his report on sexual behaviour.

Our population (random sample)

Evaluation by electronic data processing covered the completed questionnaires of

117	Jet Pilots
41	Multiple Engine Prop Pilots
14	Single Engine Prop Pilots
45	Helicopter Pilots
217	= Total

Judged by age and years spent in aviation the distribution of the groups was normal, approximately half of them had been flying for more than nine years. However, there were also an adequate number of beginners and advanced pilots.
On an average

Multiple Engine Prop Pilots	had flown	1.400 hours,	
Single Engine Prop Pilos		1.250 "	
Jet Pilots		1.220 "	and
Helicopter Pilots		1.140 hours.	

Regarding the present operational flying status there was clear intra-group diversification. In consequence, commenting on the results presented below is rather valid for the four groups. To facilitate better understanding of the many figures in the tables listed, of which this paper will only deal in detail with the first and last one, a short explanation:

	Total		Jet		M.-Eng.		S.-Eng.		Helo.	
	MS	SD	MS	SD	MS	SD	MS	SD	MS	SD
1) physic.stress	3.9	1.4	3.9	1.4	3.5	1.2	4.7	1.5	4.3	1.3
2) mental stress	4.2	1.3	4.2	1.3	3.9	1.4	4.7	1.3	4.4	1.2
3) psycholog. stress	4.0	1.5	3.8	1.5	3.8	1.8	4.5	1.2	4.5	1.2

Table 1.

A high score in the Mean-Score-Column (MS) stands for a subjectively high workload on the pilots caused by corresponding stressors, and conversely a low mean-score represents a subjectively lower workload.
A high score in the Standard-Deviation-Column (SD) indicates high intra-group diversification, meaning that there are great differences on the estimated degree of workload connected with this stressor. High mean score and low standard deviation mean, that there is a relative concord concerning workload.
It is obvious that intra-group standard deviation must be smaller than that of the groups altogether since, for example, the same mission does not necessarily call for the same requirements. Low Level for helicopter pilots implies a minimum altitude of 30 ft AGL, for a jet, however,about 500 ft AGL.

R e s u l t s

First a thorough analysis of table 1 showing the pilots' assessment concerning their total workload. The question was: "How high do you rate the degree of physical, mental and psychological stress in your entire flying activity? (psychological stress includes all straining factors imposed by responsibility, flying risk, necessity of team work etc.)" At first glance it is noted, that Single Engine Pilots have the absolutely highest mean scores.
That should not be surprising, since the 14 Single Engine Pilots are almost exclusively Instructor Pilots. This job seems to be one of the most demanding of all, according to the results of a question dealing with the degree of effort in diverse missions (table 2).
Furthermore it can be seen from table 1, that obviously mental stress on jet-, multi engine-, and single engine pilots ranks highest, whereas in helicopter pilots the tendency points to an increased psychic stress. This tendency may be explained by the emotionally higher experienced risk

to which the helicopter pilot finds himself exposed. In case of engine failure or similar incidents he is required to initiate an active selfrescue action, called "autorotation".
But also with respect to physical and mental stress the scores of helicopter pilots surpass those of jet- and multiple engine pilots significantly (p = 0.05).
There is more than one explanation: one could be, that in this group the abilities are not up to par with the requirements. The causes would lie in an inefficient personnel selection and / or -assignment. Or, operating a helicopter is very demanding indeed, also on a good pilot.
At any rate it is of interest, that physical stress is assessed as being lower than a mental and psychic one. In order to verify this physiologically, the physicians would be required to verify unequivocal parameters in the body, which may not be quite simple.
Table 2 reveals something about subjective stress during various missions. Let's only discuss them in brief, although tables 3 to 8 do not lend themselves for long discussion, but are intended as an additional source of information to enable you in a thorough scrutiny back home to check our conclusions presented in the final part.

Table 2 Subjective Stress During Various Missions

	Total		Jet		M-Prop		S-Prop		Helo	
	MS	SD	MS	SD	MS	SD	MS	SD	MS	SD
1) IFR-Flight/Hood	3.3	1.5	3.2	1.4	3.5	1.6	---------		4.7	1.1
2) IFR - Night	3.3	1.5	3.3	1.5	3.2	1.6	---------		4.8	1.0
3) Formation/Day	3.5	1.7	2.8	1.4	4.5	1.8	3.4	1.8	4.7	1.1
4) Formation/Night	4.6	1.3	4.5	1.4	5.2	1.2	---------		5.5	0.8
5) Tact. Formation	2.9	1.7	2.2	1.5	3.9	1.7	---------		4.1	1.1
6) Low-Level/Day	3.0	1.7	2.6	1.5	2.9	1.7	3.4	1.2	4.3	1.6
7) Radar-Low-Level/Day	---------		2.6	1.6	---------		---------		---------	
8) Radar-Low-Level/Night	---------		3.5	1.7	---------		---------		---------	
9) Close Air Support/FAC	---------		3.0	1.7	---------		---------		---------	
10) Intercepts ⁺+	---------		2.7	1.6	---------		---------		---------	
11) Instrument-Check-Flight	3.8	1.5	3.8	1.4	3.9	1.7	---------		4.2	1.5
12) Tactical Check Flight	3.5	1.5	3.6	1.6	3.1	1.6	2.1	1.6	3.9	1.4
13) Low Level Sea	3.0	1.9	2.6	1.8	3.2	2.0	---------		2.0 +	1.4
14) Montain-Flight	---------		----------		---------		---------		4.8	1.2
15) Cargo Drops	3.6	1.9	---------		3.3	1.9	---------		4.3	1.5
16) S A R	3.3	1.7	---------		3.0	1.6	---------		3.6	1.7
17) Long-Range-Flights	---------		---------		4.2	1.8	---------		---------	
18) IFR-Formation Flight	4.3	1.7	4.3	1.8	3.0 +	1.0	---------		5.2	1.0
19) Autorotations	---------		---------		---------		---------		5.1	0.9
20) VFR - Night Flight	---------		---------		---------		4.5	2.0	4.9	0.9
21) ACT (Air Combat Tr.) ⁺+	---------		4.9	2.2	---------		---------		----------	
22) Instructor Flying (39 I.)	4.6	1.1	4.4	1.2	4.7	1.1	4.8	0.4	5.3 +	1.0
23) "Range Only" ⁺+	---------		4.9	1.5	---------		---------		---------	

⁺+ possibly with weapons and camera + = less than 5 check marks.
In general an MS difference of more than .5 is sign. in the 5%-level.

Table 2 indicates the subjectively experienced strain resp. stress during various missions. The question posed to the pilots was: "Which missions strain you and to what extent?"
It is clear, that the "Helicopter-Night-Formation-Flight" is obviously the most demanding mode of operation altogether. It is followed by Night-Formation-Flight in Multiple-Engine-Propeller-Aircraft, Training-Flights with Helicopter-Students, Helicopter-Formation-Flights during IFR-weather conditions and only then by some jet missions such as Air Combat Training (ACT), Gunnery and Night Formation Flying. The least scores of strain seem to be attributed to missions such as Jet Tactical Flight and Tactical Check Flights in Single Engine Prop Aircraft. Your attention is invited to table 3, which has provided some surprises.

Symptoms of tension (apprehension) = Table 3

	Total		Jet		M-Prop		S-Prop		Helo	
	MS	SD	MS	SD	MS	SD	MS	SD	MS	SD
1) Gastric Disorders	1.0	1.5	1.1	1.5	1.3	1.9	0.2	0.6	0.5	1.0
2) Headache	0.9	1.5	0.6	1.2	1.2	1.6	0.7	1.7	1.1	1.5
3) Diarrhea	0.3	0.8	0.3	0,6	0.4	1.3	0.4	1.3	0.1	0.6
4) Moist Hands	1.6	1.6	1.4	1.5	1.5	1.7	1.6	1.5	2.1	1.5
5) Lack of appetite	0.7	1.3	0.8	1.4	0.8	1.3	0.4	1.1	0.6	1.3
6) Airsickness	0.2	0.5	0.2	0.6	0.3	0.6	0.1	0.3	0.1	0.4

7) Narrowing of mental channel capacity	0.4	0.9	0.5	1.0	0.5	0.9	0.4	0.9	0.3	0.7
8) Desire that flight be cancelled	0.4	0.8	0.4	0.7	0.3	1.1	0.2	0.6	0.3	0.7
9) Desire that flight come to an end as soon as possible	0.5	1.0	0.4	0.7	0.9	1.5	0.4	1.1	0.6	1.2
10) Inability to sit still	1.0	1.4	0.9	1.3	0.9	1.4	0.7	1.1	1.3	1.9
11) Pain in the eyes	0.4	1.0	0.4	0.9	0.6	1.3	0.2	0.6	0.3	0.8
12) Heart consciousness	0.9	1.3	0.9	1.2	0.9	1.3	0.7	1.3	1.0	1.3
13) Sleep disorders	0.5	1.1	0.6	1.3	0.5	0.9	0.0	0.0	0.5	1.2
14) Shaky knees	0.4	0.8	0.4	0.9	0.6	1.1	0.1	0.5	0.2	0.5
15) Increased appetite	1.2	1.7	1.3	1.7	1.1	1.6	1.1	1.9	1.2	2.0
16) Change of mood - negative	0.5	1.0	0.5	1.0	0.5	1.0	0.1	0.3	0.5	1.1
17) Euphoria	2.9	2.0	3.1	1.9	2.7	1.9	2.7	2.0	3.2	2.3
18) Own observations: the only one stated by the pilots: "Nicotine" = increased desire to smoke (49 subjects).	4.1	1.4	4.3	1.3	4.3	1.5	6.0	0.0	3.8	1.5

The corresponding question is: "Nearly all pilots experience a certain tension prior to flight. The following list contains various symptoms of tension. Please assess yourself, whether and to what extent the symptoms apply to you."
It is surely most spectacular, that -without this item being listed in the questionnaire- 49 pilots spontaneously entered in the free line provided under number 18: "Increased desire to smoke". Any smoker knows, that the yearning for a cigarette is very pronounced immediately before or after a highly stressing task.
Furthermore it must be noticed, that "Moist Hands" were admitted as the only, weakly pronounced tension symptom.
The elevated underlying mood, even euphoria because of the impending flight, seems to be clearly predominant. This is shown by the scores of item no. 17.

Tables 4 = Environmental Stressors, 5 = Ergonomical Stressors, 6 = Mission Stressors, 7 = Task Stressors, and 8 = Emotional Stressors provide information on a series of special stress factors to which pilots of such diverse aircraft types find themselves exposed.
The question is: "To what degree do you feel stressed <u>during</u> a mission by stress factors listed below?"

Based on table 4 = Environmental Stressors it becomes evident that air temperature is often felt to be very stressing by helicopter pilots. In fact measurements in helicopters have revealed temperatures of 140° F, if the helicopter had to hover on a summer day and the sun was directly shining into the cockpit.

	Total		Jet		M-Prop		S-Prop		Helo	
	MS	SD	MS	SD	MS	SD	MS	SD	MS	SD
1) Air temperature	3.5	1.8	3.2	1.8	3.3	1.7	2.9	1.6	4.3	1.5
2) Humidity	3.0	2.0	2.9	1.9	2.6	1.9	3.3	2.1	3.5	1.5
3) Noise	2.8	1.9	2.4	1.8	3.3	2.2	2.3	1.7	3.7	1.8
4) Vibration and Aircraft motions through turbulence	2.8	1.8	2.0	1.5	3.9	1.7	1.4	1.5	3.9	1.2
5) Odour	1.4	1.6	1.4	1.6	1.2	1.7	1.3	1.3	1.3	1.6
6) G-Forces	1.4	1.9	3.3	1.7	1.2	1.3	1.7	1.5	0.8	1.3
7) Air Pressure Fluctuations	1.9	1.8	2.4	1.7	1.7	1.9	1.0	1.5	0.9	1.3

Table 4: Environmental Stressors

In table 5 = Ergonomical Stressors, item no. 13 shows that sitting comfort in helicopters of the Federal Armed Forces is completely lacking. It is a fact, that the construction of the plastic seats prevents ventilation completely, causing an even unstrained observer to sweat profusely on his back after a short period of time. This could easily be remedied. Item no. 9, wearing of the "Frankenstein", the Mark 7 Pressure Suit, was obviously a torture for the jet pilots. Recent experiences with the Mark 10 are better.

	Total MS	Total SD	Jet MS	Jet SD	M-Prop MS	M-Prop SD	S-Prop MS	S-Prop SD	Helo MS	Helo SD
8) Cramped for space (Lack of motion)	1.9	1.9	1.9	1.9	2.1	1.9	1.1	1.7	2.1	1.9
9) Wearing of flying suit, (pressure suit etc.)	2.8	2.3	4.1	1.9	0.9	1.5	0.6	0.9	1.7	1.9
10) Parachute harness	1.9	1.7	1.9	1.5	2.4	1.9	1.3	1.7	1.5	2.0
11) Live Vest	2.9	2.0	3.6	1.5	2.6	2.0	0.3	0.8	0.8	1.6
12) Headset	1.8	1.6	1.3	1.4	2.6	1.8	1.6	1.7	2.6	1.5
13) Seating conditions	2.8	2.0	2.1	1.7	3.5	1.9	1.6	1.3	4.5	1.7
14) Illumination	1.1	1.4	1.4	1.5	1.0	1.4	0.6	0.9	0.6	1.2
15) Dimmed lighting without external vision	1.3	1.5	1.6	1.5	1.1	1.5	1.0	1.3	0.6	1.5
16) Instrument Layout not optimal	2.5	1.8	2.8	1.8	1.9	1.6	1.5	1.6	2.7	2.0

Table 5: Ergonomical Stressors

From the scores in table 6, Mission Stressors, it may be deduced, that quite often it is not flying itself, which is felt to be stressing, but the accompanying circumstances, such as the irregularities of the meals or fatigue during prolonged flights.

	Total MS	Total SD	Jet MS	Jet SD	M-Prop MS	M-Prop SD	S-Prop MS	S-Prop SD	Helo MS	Helo SD
17)Fatigue due to duration of flying	3.2	1.7	2.5	1.6	4.6	1.4	2.1	1.5	3.9	1.3
18)Fatigue due to monotony of job	1.9	1.6	1.4	1.5	2.6	1.6	1.4	1.4	2.5	1.7
19)Night flying	2.8	1.8	2.9	1.8	2.4	1.9	1.8	1.9	3.2	1.7
20)Irregularities of meals	3.3	2.1	2.9	2.0	4.7	1.8	1.6	1.4	4.5	2.1
21)Qualities of meals	2.8	2.1	2.4	1.9	4.1	1.9	1.9	2.0	2.9	2.3
22)Sleep deprivation during flights abroad across time zones	1.7	1.7	1.4	1.4	2.8	2.1	0.7	0.8	1.1	1.9

Table 6: Mission Stressors

Table 7 = Task Stressors (mental workload stressors) confirms the impression, that flying as a job is not felt as being to stressing. The highest score here is 3.4 and refers to the necessity of jet pilots to process information quickly and make decisions.

	Total MS	Total SD	Jet MS	Jet SD	M-Prop MS	M-Prop SD	S-Prop MS	S-Prop SD	Helo MS	Helo SD
23) Necessitiy for simultaneous concentrated supervision of various information media ("monitoring")	2.9	1.8	3.0	1.8	2.7	1.5	2.6	1.7	3.2	1.9
24) Quick information process. and decision making on a higher level	3.1	1.8	3.4	1.8	2.9	1.5	2.2	1.4	3.0	1.9
25) Handling of aircraft	1.9	1.6	1.6	1.5	2.3	1.7	0.6	0.9	2.7	1.8

Table 7: Task Stressors
(mental workload stressors)

Also the scores of table 8, Emotional Stressors, are mostly of no consequence, except the risk experience of the helicopter pilots. Here the score of 3.8 is distinctly higher than estimations of other groups regarding this possible emotional stress.

	Total MS	Total SD	Jet MS	Jet SD	M-Prop MS	M-Prop SD	S-Prop MS	S-Prop SD	Helo MS	Helo SD
26) Fear of Failure	3.0	1.6	2.8	1.6	3.0	1.6	3.2	1.8	3.4	1.6
27) Risk experience	2.7	1.7	2.5	1.8	2.2	1.4	1.7	1.5	3.8	1.4
28) Necessity for Crew Cooperation	1.9	1.7	1.9	1.6	2.3	1.6	0.6	1.1	2.0	1.8
29) Human Relations within Crew	1.8	1.7	1.7	1.6	2.3	1.7	0.7	0.9	1.9	1.7
30) Prolonged absence from family	2.6	2.0	2.6	2.0	2.5	2.1	1.9	1.9	2.8	1.9

Table 8: Emotional Stressors

Table 9 = "How I see myself and the others", contains very interesting information on how individual groups see themselves with respect to all other groups. The corresponding question was: "Make an assessment of yourself and of the other pilot groups, which follow, with a view towards total stress (physical plus mental plus psychological strain) !"

Table 9 = "How I see myself and the others"

	Total		Jet		M-Prop		S-Prop		Helo	
	MS	SD	MS	SD	MS	SD	MS	SD	MS	SD
1) F.-Bomber Strike F-104:	4.6	1.1	4.5	1.1	4.5	1.0	5.2	2.1	5.0	0.8
2) F.-Bomber Attack F-104:	4.7	1.0	4.4	0.9	4.7	1.0	5.2	1.2	5.2	0.7
3) F.-Bomber Attack G-91:	4.3	1.0	4.1	1.0	4.3	1.0	4.7	2.1	4.9	0.8
4) Tact.Reconnaissance F-104:	4.3	1.1	4.0	1.2	4.6	1.2	4.9	0.7	4.7	0.8
5) Tact.Reconnaissance G-91:	4.0	1.2	3.8	1.2	4.1	1.1	4.6	0.9	4.5	0.9
6) All Weather Fighter F-104:	4.8	1.1	4.6	1.2	4.7	1.0	5.3	1.0	5.2	0.9
7) Instructor F-104/G-91:	4.6	1.3	4.3	1.3	4.6	1.3	5.4	1.1	5.4	0.9
8) Cargo Jet Boing 707:	2.6	1.4	2.1	1.2	3.2	1.6	3.9	1.6	2.9	1.3
9) C.-Jet HFB 320/Jetstar:	2.7	1.2	2.2	1.0	3.3	1.2	3.4	1.4	3.0	1.1
10) Transall C-160	2.9	1.2	2.3	1.0	3.9	1.1	3.8	1.2	3.2	0.9
11) Instructor M.E.Prop	3.6	1.2	3.1	1.1	4.0	1.0	4.6	1.0	4.2	0.9
12) Noratlas ND 25	3.0	1.2	2.5	1.0	3.9	1.1	3.8	1.2	3.1	1.0
13) Do 27/Piaggio 149 D	2.1	1.2	1.5	0.9	2.4	1.2	3.4	1.2	3.0	0.9
14) Instr.Single Egine Prop:	3.1	1.3	2.5	1.1	3.3	1.0	4.5	1.4	4.0	1.1
15) Helicopter UH 1 D	3.5	1.3	3.0	1.2	3.7	1.2	4.1	1.0	4.6	1.0
16) Helicopter Alouette II:	3.4	1.3	2.8	1.2	3.5	1.2	3.7	1.0	4.5	1.1
17) Helicopter Instructor	4.0	1.1	3.5	1.4	4.1	1.1	4.6	1.1	5.2	0.7

You will immediately notice, that as a rule jet pilots score themselves lower than judged by other groups.
Jet groups themselves will assess nearly all other groups lower than these judge themselves and also as they see themselves mutually.
The reason may very well be found in the curious German flying system, which until recently was based on the law "supply and demand" and which has caused the formation of certain images: the saturated pilot, in our case the jet pilot, will understate his own stress but also that on other non-saturated groups. These in turn are baffled by the high flying pay of jet pilots, will consequently score them very high and will now see themselves in relation to them. This may possibly result in overestimation.
The scoring differences, however, are not of such a magnitude as to make them useless for a concluding overall summary.

C o n c l u s i o n

The final calculation was accomplished as follows:
We computed average scores for
- the five most demanding missions in each group
- all Environmental-, Ergonomical-, Mission-specific-, Mental-, and Psychological Factors, which have been provided with a check mark
- all intra-group judgements
- jet pilots' assessment of other groups
- inter-group judgement without jet pilots
- overall assessments with jet pilots and
- intra- and inter-group judgements.

Thus we arrived at a combined scoring table for all intra- and inter-group assessments regarding all specific stress factors and the overall workload.
Next we converted these scores into percentages, assigning 100% to the group with the highest score and putting the other groups in relation to it. This does not imply, that the highest group is charged with a workload of 100%, or overstressed to 100%. It merely means having a basis for comparison !

Final Score

100 %	=	Jet Pilots
95 %	=	All Instructor Pilots
90 %	=	Helicopter Pilots
75 %	=	Multiple Engine Prop Pilots
60%	=	Single Engine Prop Pilots

(5 % - round off!)

This final result substantiates our expectations to a high degree. The comparatively low score of the Single Engine Prop Pilots may be considered as being realistic, provided it is confined to the flying activities of a "simple" pilot on a single engine prop aircraft. The instructor activities rate high also on these aircraft types. The profiles of workload are characterized by missions and types of aircraft and are typical for all pilot groups. This is substantiated by the tables.
In contradiction to the high assessment of flying stress on part of the pilots and also contrary to experiences by Flight Surgeons and Aviation Psychologists we find, that psycho-vegetative symptoms (table 3) as necessarily resultant signs of stress are minimized, and this is done by all pilot groups to the same degree.
The physical workload in its entirety is unanimously assessed lower by pilots than mental and emotional("psychological") workload.
The jet pilot is mainly occupied with monitoring and decision making, the helicopter pilot with aircraft handling, and the multiple Engine prop pilot is forever confronted with his responsibility for his passengers, equipment etc.

With all the reservations towards the subjectivity of questionnaire findings on mind, it may nevertheless be concluded, that this study is not without a certain relevance.

As part of an extensive research at the GAF Institute of Aviation Medicine it has surely contributed to reduce bias. This bias had resulted in grossly unjustified classifications of flying jobs when determining flying pay.
At least our study served the purpose of adjusting flying pay in line with our percentage.
For a long time the pilots were satisfied with the outcome, or is there a better way to handle this problem?

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DISCUSSION

R.A.Albanese: Did jet pilots judge both jet workload and helicopter workload and vice versa? How did the judgements compare?

H.-P.Goerres: Yes, all pilots judged each other. Judgements did show consistent differences.

ROUND TABLE DISCUSSION

R.Auffret: Les études de charge de travail évoquées au cours de notre session font appel à diverses méthodes de mesures plus ou moins corrélées avec les charges de travail des pilotes.

En résumé, dans les communications entendues, ont été pratiquées:

- Mesure des mouvements de la tête et des yeux pour connaître la prise d'information.
- Mesures physiologiques: variations métaboliques et endocriniennes, arythmie cardiaque . . .
- Mesure de la performance: écart par rapport à une trajectoire idéale, acquisition de la cible, réussite de la mission . . .
- Tâche secondaire pour connaître la disponibilité du pilote.
- Méthodes subjectives par questionnaire dirigé: fatigue, humeur, sommeil . . . et par questionnaire (Cooper-Harper) sur performances.

De nombreuses situations opérationnelles ont été évoquées:

- Vol à basse altitude, en rase mottes (Nap of the earth), sur hélicoptère.
- Vol de longue durée et déplacement transocéanique.
- Pilotage et atterrissage sans visibilité, et du nuit, sur hélicoptère.
- Comparaison et choix des modes de présentation des informations.
- Apportage sur porte avions.

Devant le grand nombre de méthodes et d'études, le médecin, l'ingénieur, l'ergonomiste de l'aéronautique ont certainement des difficultés à choisir l'expérimentation la mieux adaptée. Cependant, il nous est fréquemment demandé d'étudier et de comparer la charge de travail d'un pilote avec plusieurs modes de présentation des informations. Dans telle situation opérationnelle, quelle méthode de mesure allons nous mettre en oeuvre pour informer au mieux les "financiers" chargés du choix des programmes ou bien le commandement qui a besoin de savoir si telle mission est ou non dans les limites de possibilités humaines.

Ne serait-il pas possible, dans quelques situations aéronautiques particulières de citer et de hiérarchiser les méthodes pratiques et réalistes d'étude de la charge de travail? Cette tentative pourrait servir de début d'uniformisation des techniques employées dans nos divers pays. De plus, toute méthode subjective de mesure ne doit-elle pas être corrélée avec une méthode objective?

Je souhaiterais demander à Mr Sanders et Mr Lovesey quelles sont les mesures les plus intéressantes à effectuer sur hélicoptères dans le vol à basse altitude.

E.J.Lovesey: I think probably I had better start by saying what not to do; I think the only reason why I have been allowed to fly with the British Army is because I am the lesser of two evils.

By my passive filming I replaced a rather more active method. I understand that, before me, during nap-of-the-earth flying they used to take blood samples and I think it did rather distract the pilot. Nevertheless, if by "nap-of-the-earth flying" you mean a helicopter low-altitude flight, I think we must be really careful not to do anything to distract the pilot. Therefore, the methods must be fairly passive, and so there will be objective methods such as measuring the aircraft performance and ability to fly a certain flight profile – these, I think, must be done, although it is very difficult from these measures always to know exactly how hard the pilot finds it. We heard from Wing Commander Nicholson, the other day, of the method of analysing speech patterns and in fact there are one or two promising methods coming along which I think are ideally suited to evaluating pilot workload, because all we have to do is just plug into the intercom; the pilot is not affected in any way. Once we start attaching things to the pilots then, of course, we run the risk of influencing his workload and his performance. Again, I take your point; I think that, as well as having objective measures, passive or otherwise, we must always back these up and try to correlate them with subjective measures. We have heard of one or two such methods here today. But, whatever we do, we must not change the activity pattern of the pilot by measuring whatever he is doing.

R.Auffret: Merci Mr Lovesey d'avoir insisté sur un point qui me parait capital: l'impérieuse nécessité de ne pas interférer avec le travail du pilote par un enregistrement pénalisant et stressant qui risque de fausser les mesures.

Mr Sanders voudrait-il ajouter quelques mots?

M.G.Sanders: I agree with Mr Lovesey. I believe that it is highly critical that we do not interfere with the operational or in-flight performance of the aviator during his performance of various missions. But I do think that it is important to evaluate exactly what the problem is. The question of what measurement technique should be used on low-altitude flight is a very general one because, in our situation, we are forced to respond to questions or problems that deal with the great many different activities involved in low-altitude flight. So the kind of measurement techniques you might utilise greatly depends on the problem area itself. If one is forced to evaluate problems pertaining to the pilot, we would have to consider primarily those activities related to psychomotor performance such as aircraft inputs or control inputs, as well as engine and aircraft status, such as Dr Lees reported earlier. Because his duties are primarily psychomotor,

that would be the first area to investigate. However, during the first session, Mr.Simmons presented a film illustrating the visual activity of the pilot during low-altitude flight, and it was quite evident then that the visual workload was a significant factor in his performance of that duty. Moving on to the co-pilot, his duty is primarily a visual and information-processing one. However, it could be that the verbal or auditory factors or sensory modes should be examined a great deal in both the co-pilot and pilot performances of these operations. In general, we feel that the objective measures are the primary tools for evaluating performance in flight. But there are always situations in which the subjective measures must be utilised to help us better understand the problems and apply more correlation between our objective data and the subjective feel of the pilots.

R.Auffret: La connaissance de la prise d'information visuelle du pilote est évidemment essentielle lors des vols basse altitude en hélicoptère. Malheureusement les systèmes oculomètres actuels sont difficilement supportables pendant plus de 10 minutes.

Dans les vols de longue durée, Mr Hartman, quelles sont les mesures les plus utiles à effectuer pour apprécier et quantifier le travail des pilotes?

B.O.Hartman: From my point of view, when you are talking about extended flight, it becomes extremely important to deal with the total environment in which the man finds himself operating, the mission situation with which he is confronted, and the total amount of work which he has to perform; I include lots of things in workload that I have not heard discussed here today. For instance, there is a certain amount of work in simply maintaining the body and keeping it functioning. There is a little bit more work in just standing around; if you are standing around, waiting for a clearance or a command, there is even a lot more work because emotional factors come into play. You have to take these things into account. You are also confronted in the long-duration situation with the same thing that was discussed earlier in connection with helicopter work; that is, you must avoid interfering. You must avoid interfering with the mission, you must avoid interfering with the tasks being performed by the crew member in his typical way. Finally, a factor which always needs to be considered is the capability of the Laboratory that is involved in the study; the fact is that we cannot make measurements that we do not know how to make. Every Laboratory is somewhat different in this respect. I think a full battery is possible in the extended flight situation, to include biochemistry, physiology and psychophysiology. Performance assesments at intervals, particularly for critical segments of the mission, over a period of days, for instance, are valuable. One might choose, in a transport situation, to look at every approach and landing, and do some kind of objective or subjective rating or data acquisition in that situation, and follow the crew members throughout the entire 24-hour period, using activity logs and other kinds of measures of what is going on, with some of the measures representing on-going activities and biomedical orientation, such as biochemistry, and other measures representing samplings, such as rating on approaches and landings at regular intervals.

R.Auffret: Avec mes remerciements à Mr Hartman pour ces intéressants commentaires je souhaiterai donner la parole à Mr Vettes, pour lui poser la question suivante:

Dans le cadre du pilotage et de l'atterrissage sans visibilité sur hélicoptère, quelles sont les méthodes de mesure les plus adaptées à l'étude de la charge de travail?

B.Vettes: Au cours du pilotage, et plus particulièrement de l'atterrissage sans visibilité sur hélicoptère, la charge de travail est un peu spéciale.

En premier lieu, il nous parait donc indispensable de disposer d'une méthode de mesure de performance qui permet le calcul de l'écart par rapport à une trajectoire idéale définie.

En second lieu, la mesure d'un paramètre physiologique, la fréquence cardiaque instantanée et la variabilité cardiaque, nous paraissent particulièrement indiquées. En effet, au cours de cette approche l'effort physique est réduit et il s'agit plutôt d'une tâche intellectuelle et perceptive, ce que traduit parfaitement l'étude de la variabilité cardiaque.

En troisième lieu, associée à ces méthodes objectives, il est bon de réaliser une méthode subjective de type questionnaire à la condition qu'il soit simple et réalisé en accord avec les membres de l'équipage.

En quatrième lieu seulement, viendrait une étude du mouvement des yeux, car dans ce type de tâche le déplacement oculaire n'est pas important.

R.Auffret: Le choix des présentations d'information est un des problèmes le plus fréquemment posé. Ce choix de nos jours est presque uniquement réalisé d'après les avis subjectifs des utilisateurs. Certaines méthodes objectives ne sont-elles pas utilisables, Mr Beyer?

R.Beyer: I would hesitate to give any list of priorities of workload measurements. In the field of designing displays it depends too much on the specific applications. We have heard today a number of papers concerned with helicopters, and they are a very good example, because you can measure variabilities around the helicopter; it may be in the field of stabilisation, or in the field of maintaining given heights, speeds and so forth. So I think it is worth looking first at the variabilities with respect to a given reference. For example, having ordinary VFR flight as a reference, you can measure how the pilot and how the helicopter are doing on a simulated IFR using some exhaustive displays. Then it is worth looking at those variabilities which may be reduced, that is, by a better layout of the display or by giving more automation to the automatic control system or by asking the pilot to do all the things manually. For example, the

outcome of our investigations was that we need indeed stabilisation of the helicopter, and in the field of fixed aircraft there are similar problems. For example, by optimising flight manoeuvres within the total energy concept, a specific display is again needed which takes the guesswork from the pilot and gives him usable and flyable information. So the major point is that the highest priority, if we go to priorities, is the information content rather than the layout of the display. Of course, the layout is also of importance but first one should consider the information content and this is, I think the only priority I would give in this respect; then one has to form one's own criteria and workload measures for the specific application. As I said, it is not possible to apply a specific measure to each different application or operational case. One has to look at the details of the mission and then to apply or develop measures which are relevant to this case. But I have a more general comment. My feeling was, looking at some of the papers, that we have heard, for example in the last 10 years, quite a lot about heart-rate variance, and something about critical fusion frequency; there are very sound investigations and one can decide to apply these measures or not to use them. So we could not gain much more experience from some of the papers we have heard today and, in particular, from those papers dealing with subjective ratings.

I recall an AGARD conference about five years ago where we discussed the same problems and some speakers offered solutions; I would like to see those solutions more applied, rather than going into the details of research on these measures again and again. There must be some stage where we accept these measures as they are or we do not use them. So I am really asking what progress we have made in the last five years in this respect. Are we able to discriminate between those measures we are going to use and those which are definitely useless? I think this communication has not taken place so far.

R.Auffret: Je crois que Mr Beyer est un peu pessimiste et que des progrès certains ont été réalisés depuis 10 ans sur le sujet; néanmoins, je suis d'accord pour dire que beaucoup reste à faire.

Mr Brictson peut-il nous dire quelques mots des problèmes particuliers aux porte-avions, sujet qu'il étudie depuis de nombreuses années et qui représente des conditions de travail particulièrement délicates.

C.A.Brictson: Yes, I would agree with the earlier comment that it is time to assess the validity and reliability of some of our instruments. I think that some of the papers presented here have done just that; I would stress the need for continuing measures of performance and assessment of workload in order to relate what influence different workload levels have on performance, both short term and long term, in terms of decrement; in terms of carrier landing, I would promote the idea of daily workload activity scales, of subjective estimates of mood and sleep levels as being indicative of the pilot's stage of temporal readiness. I do believe, in view of what Dr Hartman mentioned, that from time to time we must revalidate some of these techniques, so that the need for biochemistry measures certainly would be in order to determine the adequacy of subjective reports over time. But I do see that there has been some progress made in the last five years. I see this to be a much more lively interchange of information and must note also that sometimes we only make progress through mistakes; so that some of the critical comments can be well taken by all of us to look at our techniques and our methodology a little more critically, so that the results that we do promote have some application both to the user and to the scientific community.

R.Auffret: Merci, Mr Brictson de nous rassurer sur la validité de nos travaux et d'avoir su mettre en lumière l'intérêt des échanges d'infromations entre les spécialistes des divers pays NATO. Mr Steininger et Mr Goerres, j'aimerai vous poser la question suivante:

Dans quelle situation aéronautique peut-on attendre le meilleur résultat des méthodes par questionnaires?

K.Steininger: We have to realise that there are many different types of questionnaires and this is not the place to specify them. As far as my opinion and my experience are concerned, I must say that a questionnaire should always be used if more detailed information is required about different mood and motivation backgrounds of a pilot going to perform flight missions and after completing them. That is to say, all sorts of tests must be made on the fatigue during the particular mission, on the one hand, and on the demand of particular tasks on the other hand.

With reference to application, the questionnaire should be used to check out the comfort and the acceptability of a particular flight system or subsystems, from the human engineering point of view and to choose the right one, that is, the most acceptable. It is always right if certain important principles and methodology for the application of questionnaires are well established and if a sufficient population sample for the statistical evidence and the reliability of the data collected can be guaranteed; in order to cope with subjective ability aspects of well-structured information from pilots we must not rely on extremely sophisticated applications of the strongest statistical rules, which are applicable only for experimental research.

H.P.Goerres: I think the problem is that we should not take only one method and say it is the best one – questionnaire, biochemistry and so on. If we have a situation also in the field of motivation, we should be able to add all possible methods together in measuring or assessing pilot workload.

R.Auffret: Avant de clore cette session, une question pourrait servir de liaison entre les deux sessions de travail consacrées aux "méthodes et études de la charge de travail". Il s'agit des corrélations existant entre les méthodes et mesures psychomotrices, psychométriques, psychophysiologiques et physiologiques. Ce sujet pourrait faire l'objet d'un groupe de travail étant donné sa complexité et son importance. Mr Hartman, à qui je me suis permis d'en parler, a bien voulu accepter de répondre à cette question très délicate.

B.O.Hartman: I do not know whether we should give this a little bit of thought or a lot of thought.

I have been intensely interested in this general problem for some time, because in the work I have done, and in the work I follow most closely, we have many disappointments and a wide range of techniques and I often wonder how we bring all these things together; how can we? I become convinced over the years that if we have the operational problem of executing all the performance measures we desire and nobody could interfere or stop us from doing anything, we could indeed find situations in which, in particular, the psychomotor measures, or the objective performance measures if you prefer, the psychophysiological measures and the physiological measures would come together and support each other; and then, I can think of situations where they would not. Sometimes, for example in the question of an optimal display, a measurement from the physiological doman might not contain enough information to make it cost-effective, or, for example in using urine biochemistry, the duration of the mission is so short that you do not get enough urine to make it worth while analysing it. I think you can see the kind of things I am thinking of. But I think it would be possible to build a three-dimensional matrix in which one dimension would be the operational system we are dealing with; another dimension would be the mission requirements that we are dealing with and then the third dimension is something I have not defined very well but it would be, broadly speaking, the biomedical techniques and technology which we can bring to bear on the problem. If we did this we could find where there would be a substantial amount of agreement and support from the various disciplines, leading to common findings; then we could find the borderline areas where that begins to break down and lastly the areas where it would not work at all. I should like to see the working group consider that one, and see whether it could be constructed, and then, if that looks pretty interesting, to see the Aerospace Medical Panel sponsor a NATO experiment. If we really do this, I think the critical area is the border line, where the various disciplines and approaches begin to separate out from each other. We could see if we can demonstrate empirically that the matrix makes some sense. What level do I expect? Mutual support from the various approaches – psychomotor, psychophysiological and physiological. I think already we can see situations in which there is support from one approach to another at the level of conclusions, but also at the level of specific findings or results. That is, we can see support from one approach to another at the qualitative level, but not yet at the quantitative level; perhaps here, again, developing some sort of matrix and trying this out, and with some cross-Laboratory fertilisation and joined activities might give us a better feel for whether, in fact, this is a useful enough idea. The only item I have not yet touched on here is the psychometric; being a psychometrician myself, I do not know exactly what goes into the psychometric. If we include rating scales and subjective questionnaires, such as I use and such as Mr Brictson and some other folk use, then there is indeed a place for those and a total measurement battery. I am not talking about the relationships between these various approaches but rather the totality of all approaches in an integrated approach; there is a place for psychometrics in there. We are talking about the other kinds of psychometrics, the mood-scale kind of things, the personality type, personality categorisation, things that I am less impressed with as regards their potential contribution. That may well be a very personal response, because in my laboratory those latter kinds of psychometric instruments have been of very little use to us. In general, I should just like to say that in all of these areas we have an urgent requirement, whether we are doing psychophysiological studies or physiological studies or performance measures, to focus on measures that are as close as possible to the significant issues of operation effectiveness.

R.Auffret: Merci beaucoup, Mr Hartman.

En terminant cette session, je tiens à remercier tous les auteurs, tous les interlocuteurs et tous les participants de cette table ronde. Par la qualité, la précision de leurs exposés, ils ont rendu notre réunion vivante et profitable. J'avoue, personnellement, y avoir beaucoup trouvé d'intérêt et souhaite qu'il en fut de même pour la nombreuse assistance.

Merci également à nos interprètes si compétents et si aimables.

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14. Abstract

Twelve papers were presented at the Meeting.

Six related to the evaluation of the work-load on the helicopter, thus revealing the importance and the new difficulties of helicopter operational missions. They comprised a general study of the stresses peculiar to helicopter piloting (B1), the problems raised by low altitude flight (B2 and B3), by long duration flights (B4), by blind flying and landing (B5 and B6). Five papers were devoted to problems specific to aeroplanes; long duration flight in a combat aircraft in transoceanic deployment (B7), metabolic and endocrinal cost of flight in a combat aircraft (B8), new aiming system for air-to-ground firing (B9), deck landing at night during prolonged operational campaigns on aircraft carriers (B10), flight quality and work-load on a short-haul transport aircraft (B11). One paper studied by a selectively directed questionnaire the special characteristics of the work of different categories of pilots (B12).

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